Engineering Li

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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DEC 26 1940

Entrance to Buzzard Point Station, Washington, D. C.

Buzzard Point Adds 100,000 Kw in the Nation's Capital

A.S.M.E. Annual Meeting

Water Conditioning Methods and Trends

The Viscosity of Steam

Elesco Superheater with elements connected to headers by ball joints.

Elesco Girth Superheater designed for hrt boilers.

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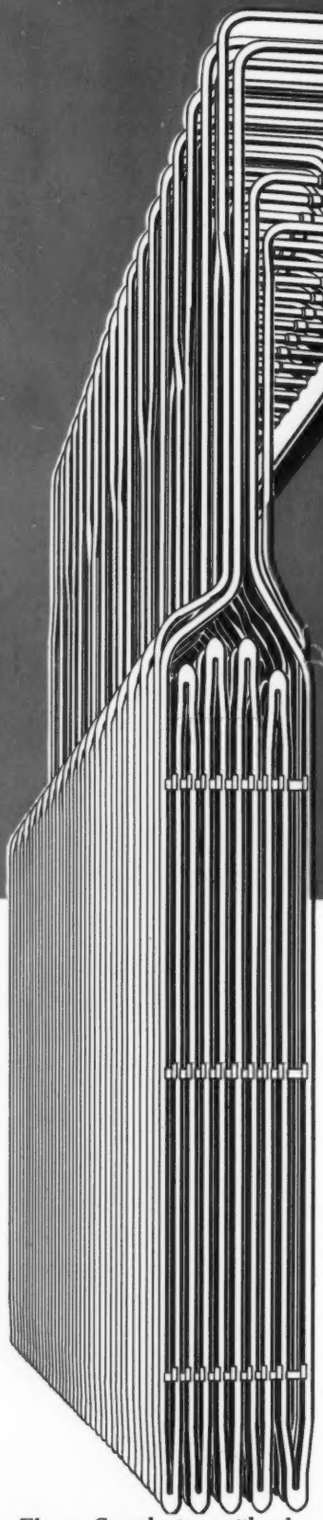

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VOLUME TWELVE NUMBER SIX

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EDITORIAL

The Market for Engineers

The Employment Committee of the American Association of Engineers has just released the results of a study of 573 placement cards of members of the Association. While the number involved is too small to form the basis of definite conclusions, and the majority of placements was confined to eight midwestern states, the results nevertheless afford some interesting deductions.

The demand for college graduates, which was most marked during the depression period, has again become normal; that is, about as it was in the pre-depression years. However, more stress is now being placed on scholastic records and sound training in fundamentals. Furthermore, there appears among the cases reviewed, an indifference on the part of both employers and applicants to professional registration.

At the present time more employers are stipulating nationality and citizenship, which fact is readily understandable in view of the prevailing situation. Also, increasing emphasis is being placed on appearance, personality and the applicant's knowledge of engineering economics.

Whereas in the late '20's there was a widespread age limit of forty years, often in disregard of experience and judgment—a practice which persisted during the depression when many older men were replaced by younger men at lower salaries—many employers now appear to be giving preference to men over forty. In fact, during the past few months men of forty-five and over are finding a much better market for their services. While Social Security may have been to some extent a factor, the general rise in industrial activity, conscription of the younger men and the demand for specialized experience have undoubtedly favored employment of the older men.

A rather unusual and unexpected situation was indicated by the increased number of engineers employed on an hourly rather than a monthly basis. No explanation of this appears, although the Committee suggests that federal and state social legislation may be responsible. It raises the question whether a substantial increase in this practice would not tend ultimately to wipe out the distinction between professional and nonprofessional employees in industry.

Average salaries, as indicated by this survey, are about 23 per cent below the 1929 level, although draftsmen and designers in certain fields are benefiting by the law of supply and demand and are therefore back to the pre-depression levels.

Of the 573 cases studied, 249 were in civil engineering and construction work, 236 were in mechanical and industrial engineering and 88 were electrical engineers. Thus the deductions, in so far as they may be taken as a partial index, apply to the major fields of engineering.

Following the subject further, reference may be made to the remarks of Dean A. A. Potter at the Annual Meeting of the A.S.M.E., who observed that there is already an acute shortage of technical and supervisory engineering talent in certain industries concerned with national defense; that there is urgent need for more men competent to design machine tools and make shop layouts; and that the Army and Navy need many inspectors who have knowledge of materials and physical testing.

Thus it would seem that those with engineering training and experience are finding an active market for their services and that the trends, as indicated by the American Association of Engineers Survey, may be carried further to the advantage of the engineering profession.

Few Courses in Marine Engineering

The Engineers' Council for Professional Development, representing the national engineering societies and the state boards of engineering examiners, has just issued its Eighth Annual Report which contains a revised list of accredited curricula of engineering colleges. Among the 125 engineering schools listed, 115 offer regular courses in civil engineering, 112 electrical, 104 mechanical, 39 chemical, 37 aeronautical, 35 metallurgical, 31 mining, 28 industrial, 28 sanitary, 20 petroleum, 14 architectural and only 3 naval architecture and marine engineering.

These figures might be taken as an index of the popularity or relative demands for instruction in these respective branches of engineering. However, with shipbuilding now becoming one of our major industries, the very small number of schools giving courses in the marine field would seemingly indicate a dearth of technically trained men to meet our rapidly expanding ship construction.

An explanation of this situation is to be found in the fact that up to about two years ago, and excepting a brief period during the World War, shipbuilding in this country for a number of decades was limited, hence it did not offer wide and attractive opportunities to the prospective engineering graduate. Under present conditions, however, the Defense Program, the Maritime Commission's vast construction program and probably to some extent replacement of foreign tonnage lost in the war will keep American shipyards busy for several years to come. Furthermore, recent advances in marine engineering practice offer broad opportunities for technically trained men.

Just as many of the colleges reacted to the growing aeronautical industry a few years back by adding such courses to their curricula, it is anticipated that they will soon respond to the present situation in the marine field.

BUZZARD POINT Adds 10

Fig. 1—Buzzard Point Station as of September 26, 1940

THE area served by the Potomac Electric Power Company lies along the northeast shore of the Potomac River. It includes the Distr.ct of Columbia, sixty per cent of the area of Montgomery County and fifty per cent of the area of Prince Georges County in adjacent Maryland.

The main sources of power are two steam generating stations in the District of Columbia and three transmission-line connections with the Consolidated Gas Electric Light & Power Company of Baltimore. The combined capacity of the steam stations is 305,000 kw.

Prior to 1940, Buzzard Point consisted of two 35,000-kw turbine-generators and two 375,000-lb per hr boilers. The recent increase in the normal load growth rate in the Washington area, plus the effect of the defense program, necessitated a speedup in generating station facilities. To meet this need, ground was broken last year for a third unit consisting of a 50,000-kw turbine-generator and a 525,000-lb per hr boiler. This unit was placed in preliminary operation on October 16 of this year. A fourth unit, now on order, and a duplicate of the third in most respects, is scheduled for delivery late in 1941. The following comments and description relate, in general, to the 1940 addition just started, but may also be equally well applied to the 1941 unit.

Designed for an ultimate capacity of 270,000 kw with six units, this station now has in operation two 35,000-kw and one 50,000-kw units, with a second 50,000-kw unit on order. The description deals primarily with this latest extension which was placed in service in October 1940.

Description of the Station

The station is designed for an ultimate development of six generating units, the two earlier 35,000-kw units, the two 50,000-kw units with which this article deals and probably two additional 50,000-kw units, or a total capacity of 270,000 kw. The unit system has been used throughout, and past experience has shown that spare boilers are not justified in modern installations. Average availability on the Buzzard Point units up to the present time has been approximately 95 per cent.

The layout is such that all major operating equipment is confined to two floors, with no wall between the turbine and boiler room. This is shown in the cross-section, Fig. 2. The boiler operating floor is at the same level as the turbine floor. By placing the firing aisle toward the turbine room, accessibility is increased and one set of operators can conveniently supervise the operation of all equipment on this level. All other rotating equipment, including the forced- and induced-draft fans, pulverizers, condenser pumps, evaporator, condensate booster and boiler-feed pumps, is located on the auxiliary floor (grade 5.5). This provides a compact arrangement with ample accessibility to equipment for maintenance and ease of operation, particularly

100,000 kw in the Nation's Capital

By C. E. MILLER
Potomac Electric Power Company

around the boilers where convenient access is most desirable. The layout was also designed to give low building height as required by zoning regulations.

Because of the extreme importance in Washington of avoiding smoke emission or the discharge of cinder or fly ash from the stack, Cottrell electrostatic-precipitator equipment, three sections deep in the direction of gas flow, has been provided instead of the usual two sections.

It will be noted that this new unit is of 50,000-kw capacity, as contrasted to former installations of 35,000 kw. Studies made on the basis of the expected load growth in the Washington area indicated that this increase in size was justified. In increasing the size of units, it was also found advisable to increase the number of extraction stages from three to four.

Steam temperature at the turbine throttle was increased from 825 to 900 F, although the former pressure base of 650 lb was maintained. The higher temperature increased the economy of generation appreciably without causing disadvantages in operation arising out of inability to interchange boilers and turbines. The new boiler is equipped with oversize controls of superheat temperature so that it may be operated at 850 F to supply the older turbines.

Heat Balance

The schematic layout of the heat balance and accompanying controls are shown on Figs. 3 and 4. Past experience with the cycle using direct-contact heaters has been very successful, so their use was continued with the new unit. Condensate is pumped from the condenser hotwell through a regulating valve to the fourteenth-stage heater. This regulating valve is positioned partially by flow of water from the hotwell and partially by the hot surge-tank level.

One stage of a two-stage booster pump unit takes the water from the fourteenth-stage heater and delivers it to the eleventh. The second stage of this same unit delivers the water from the eleventh stage through the evaporator-condenser to the hot surge tank. The booster-pump unit consists of two entirely separate pumps driven by a single motor and all mounted on a common baseplate.

The water from the hot surge tank is delivered by the boiler feed pump through the fifth-stage heater to the boiler. This heater is of the closed type with built-in desuperheating section so that the water leaving the heater is 3 deg above the actual saturation temperature of the extraction steam.

Control of the cycle using contact heaters is slightly more complicated than with closed heaters. However, the contact heaters have many advantages, for example, the feedwater is heated to the full temperature of the extraction steam. A greater quantity of steam is extracted from the turbine with a resultant lower Btu rate per kilowatt-hour. Drip pumps or degradation of energy due to cascading of drips is eliminated. The condensate is thoroughly deaerated.

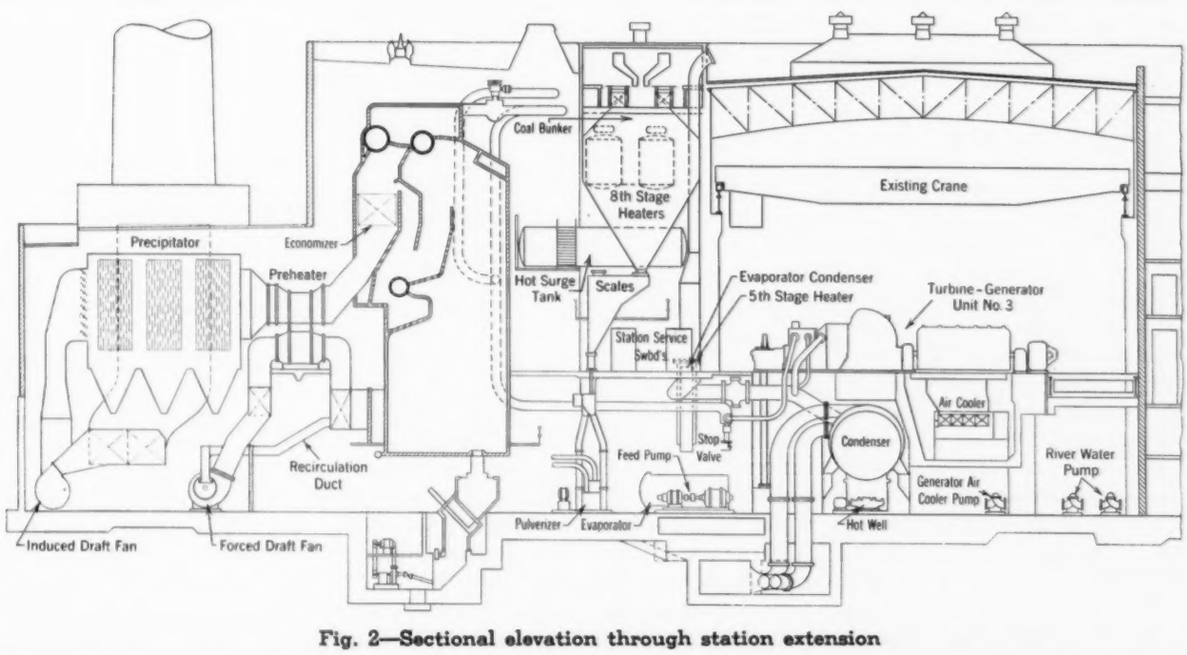


Fig. 2—Sectional elevation through station extension

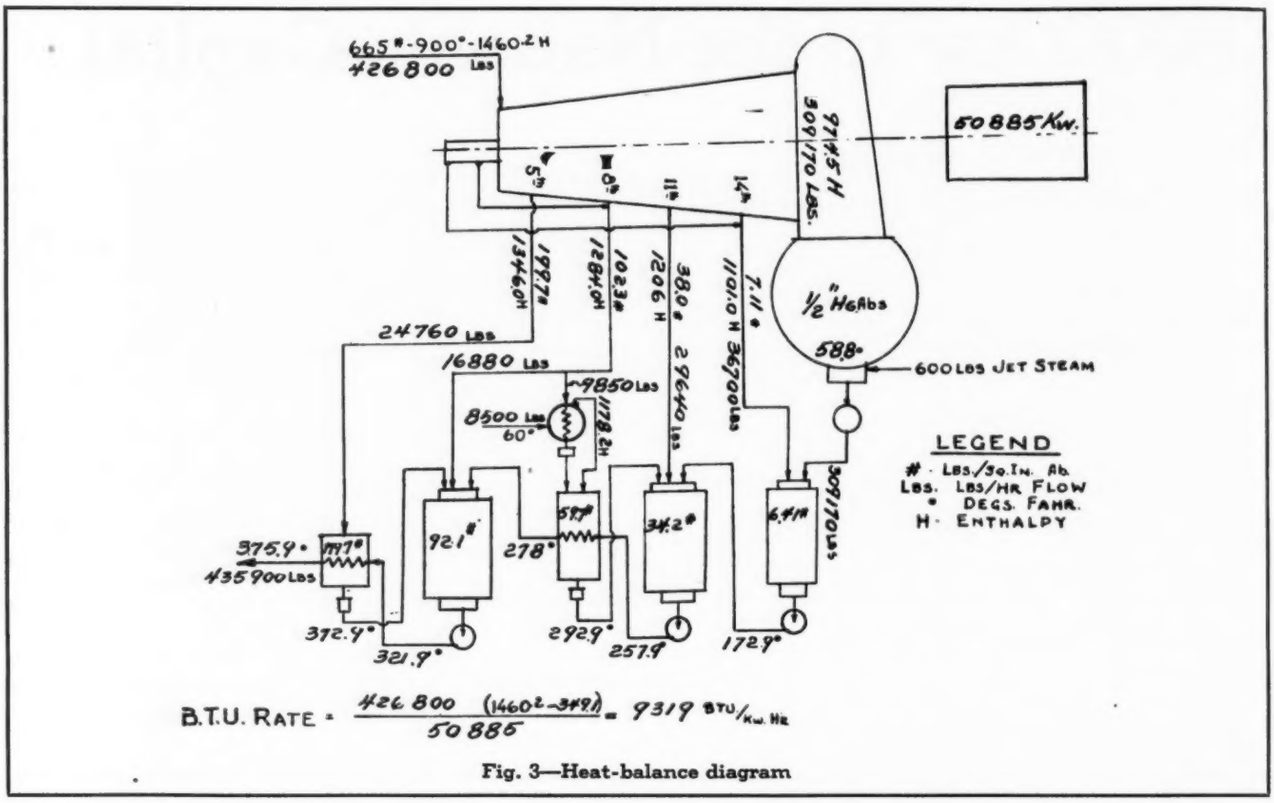


Fig. 3—Heat-balance diagram

Steam Generating Unit

A cross-sectional view of the boiler is shown on Fig. 5. This is a three-drum, bent-tube type, rated at 525,000 lb per hr with steam at 690 lb per sq in., 900 F total temperature. Many features have been incorporated in the design by the manufacturer and engineers.

The furnace has been made of ample size so that the temperature entering the first bank of boiler tubes will not exceed 1900 F at maximum output. This is well below the "sticky" point of the ash of any coal used at present so there is a reasonable assurance that no troubles will be experienced due to slag formation on the boiler or superheater tube surface. However, if a change of fuel or other causes should cause slag formation on these tubes, ample facilities for lancing have been provided by means of the doors on top of the boiler. Access and observation doors are considered of particular importance in the operation of a unit of this kind. The observation ports provided on all parts of the furnace and boiler, as well as the number and arrangement of access doors on the boiler proper, are adequate and will enable the operators to check closely the performance of all parts of the unit, as well as have easy access for maintenance when necessary.

The soot-blowing equipment has been designed to keep all the heating surface in a commercially clean condition with the boiler in service for periods of indefinite length. Past experience has shown the desirability, particularly from a maintenance standpoint, of mass blowers in the hotter parts of the furnace so units of this type are installed across the boiler top in front of the first boiler tubes. Other elements of the conventional type have been provided in the superheater, economizer and cooler parts of the boiler. Provision has been made for the future installation of wall blowers if these are found desirable, although experience at the present writing indicates that these will not be necessary.

The furnace is completely water-cooled in every sense of the word. Wall tubes are of bifurcated construction so that only about a $^1/_{16}$-in. space has been left between adjacent tubes. Because of this construction, the insulation of the wall was simplified and consists merely of a backing plate for the wall tubes, a 4-in. glass wool blanket and then the outside casing.

It should be noted also that intermediate headers in the waterwalls are entirely absent. This was done to eliminate potential sources of trouble from leaks at rolled joints and handhole caps, and remove the tendency of slag to build up at the shelf formed by the wall header. This construction required welding of the long wall tubes which is permitted in the Boiler Code. The supply tubes for all lower water-wall headers have been carried from the bottom drum outside the casing, down to the wall headers. This insures positive circulation, and therefore a more positive water supply to the water-wall tubes.

Particular attention has been given to the elimination of potential sources of leaks. Handhole caps have been eliminated entirely in the superheater and economizer headers located within the setting. Superheater and economizer tubes were field welded to short nipples in their respective headers. These nipples, in turn, had been welded into the headers at the shop and the whole unit stress-relieved before shipment. Handhole caps in the water-wall headers have been supplied with spring washers under the nut to equalize and hold tension on the joint face and gasket regardless of temperature changes. All small valves around the boiler and other parts of the station are of the integral stellited-seat construction and welded in the line.

Air leakage into the setting has been minimized by such things as installing the economizer headers within the boiler casing, covering all projecting ends of the drums with metal casings jointed to the boiler casing proper, and making up all casing joints with sealing cement.

Another innovation was the use of horizontal runs in the pulverized coal piping. This change was of considerable advantage. It decreased the cost of the piping and made it considerably easier to run these lines without interference with other piping and equipment. It also greatly increased the available floor space around the front and sides of the boiler at the boiler operating level and left more operating space and accessibility at this level.

The furnace heat release is 22,800 Btu per cu ft when operating at 525,000 lb per hr, based on an effective furnace volume of 29,500 cu ft.

Because of tie-line connections with hydroelectric plants, Buzzard Point is required to operate at minimum load during high-flow seasons of the year. Due to the difficulty of maintaining a steady fire under these conditions, it was felt advisable to make the oil ignition system completely automatic from the boiler gage board. This would enable the operator quickly to re-ignite his fire if it should go out.

The ignition system sequence of operation is as follows: The operator pushes a "start" button at the boiler gage board. This starts a fuel oil pump and at the same time, closes the circuit to the ignition spark at each oil torch. As soon as pressure reaches the burners, an oil-operated piston, through linkages, pushes the torch forward and into position. When the operator pushes the "stop" button, the spark transformers are disconnected, the oil pump stops and on loss of pressure, the burner recedes to its more protected position in the windbox. By pressing another button, the operator can blow all oil tips with steam to clear them of any foreign particles of carbon.

The load factor on this unit for the next ten years is expected to be approximately 90 per cent. Due to the comparatively high price of fuel in the Washington area, it was desirable to have this boiler unit as efficient as possible without excessive cost. In addition to the ample heat-absorbing surfaces provided in the boiler setting itself, the use of regenerative-type air heaters was a major contribution to this end. With the increased heat-absorbing capacity of this type of heater for a given volume of building space required, it was possible to obtain a steam generating unit about 2 per cent higher in efficiency than with any other type, without effect on the existing building outline and with an actual decrease in initial investment over other types.

Attention was also given in the location of the superheater bypass damper used for controlling steam temperature. It is located at the top of the setting where short linkages can be used, and at the same time is well shielded behind a major bank of boiler tubes and the superheater. Both of these factors should contribute to minimum maintenance without sacrifice of speed of control. With the damper in the position shown, it will also be noted that no separate bypass had to be incorporated in the setting.

Boiler Auxiliaries

The boiler is equipped with two forced- and two induced-draft fans, the latter being driven by constant-speed induction motors through hydraulic couplings. Studies on this system of fan-speed control showed that the saving in power justified the increased cost of the coupling over damper control. Conversely, on the forced-draft fans, due to their lower power requirements,

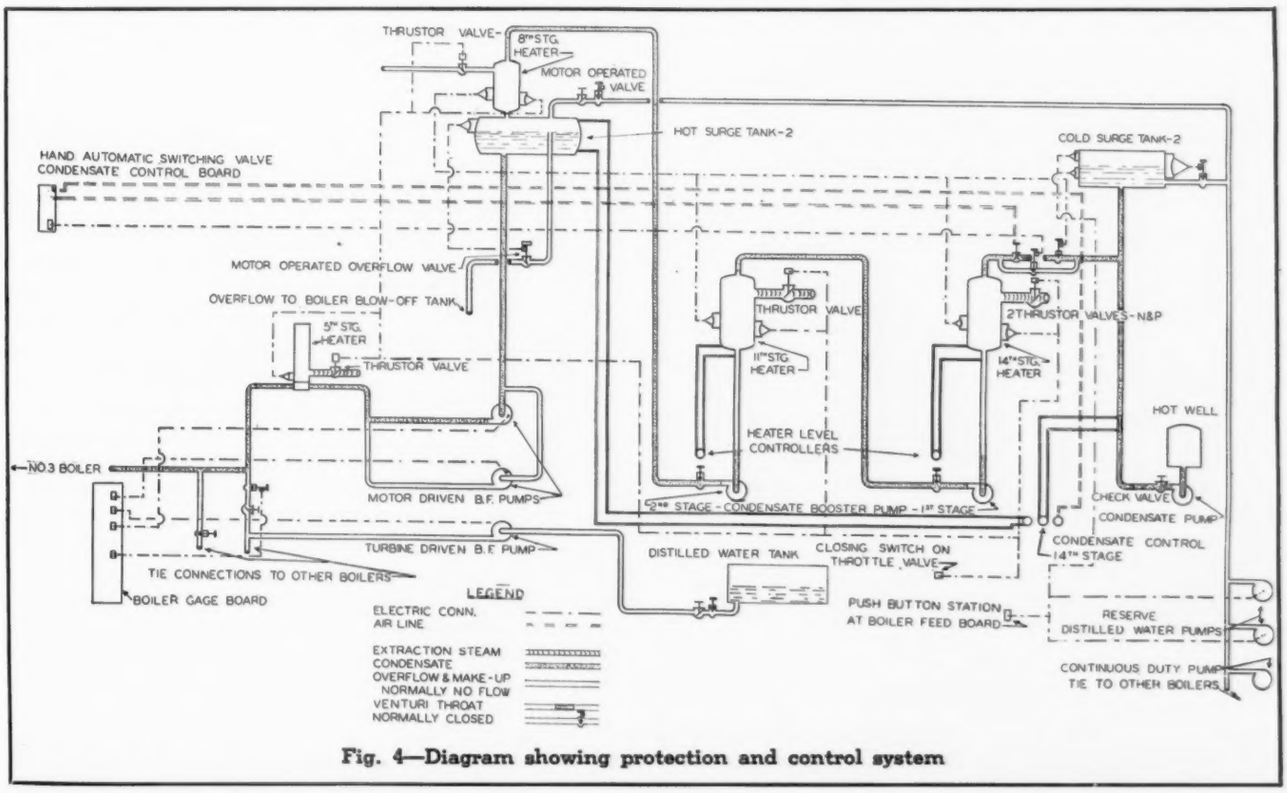


Fig. 4—Diagram showing protection and control system

the increased cost of couplings was not justified and vane control was purchased for these units. Some advantage in this arrangement was gained, also, by the utilization of the speedier response of the damper control for furnace-draft control.

The unit system of pulverization is employed. The boiler is served by three attrition-type pulverizers rated at 27,000 lb per hr. Each mill delivers to four burners located in the corners of the furnace. Coal feeders are of the rotating-drum type equipped with an automatic arrangement for keeping the bottom of the pockets clean when handling wet coal. The feeders are driven by constant-speed induction motors through a variable-speed drive. Richardson scales, provided for each mill unit, are equipped with magnetic pulleys for removing any stray iron from the fuel before pulverization.

Two boiler-feed pumps are driven by wound-rotor induction motors. Either of these pumps will handle the maximum demand on the boiler. A third steam-driven pump, taking its suction direct from the distilled water tanks, is provided for extreme emergencies in case of loss of both motor-driven pumps. Speed control

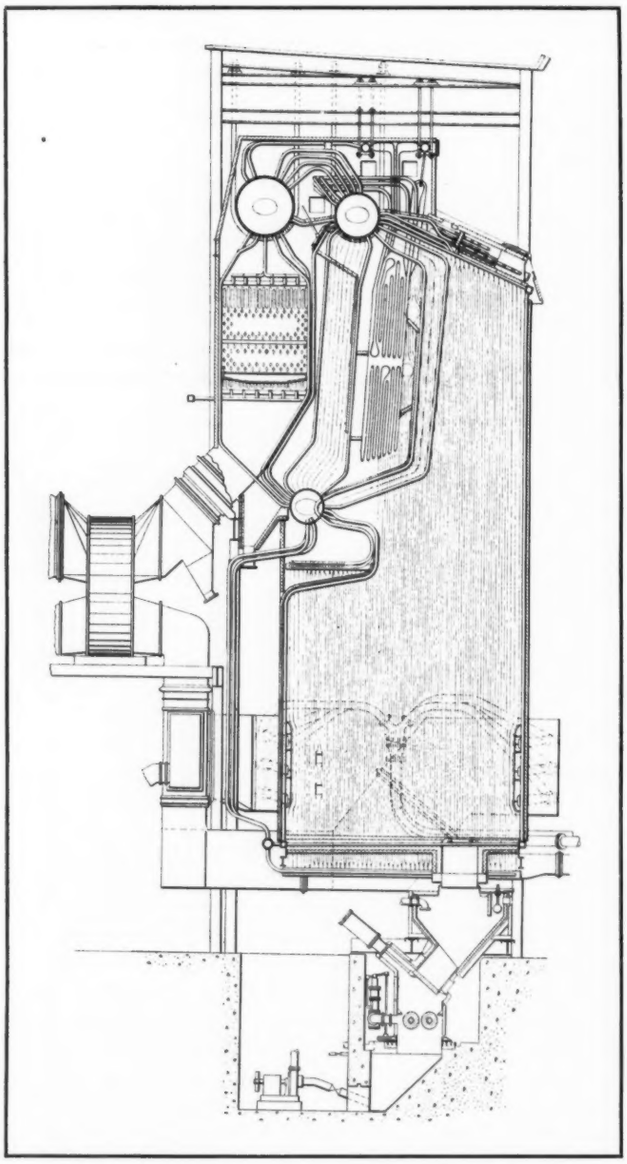


Fig. 5—Section through steam generating unit

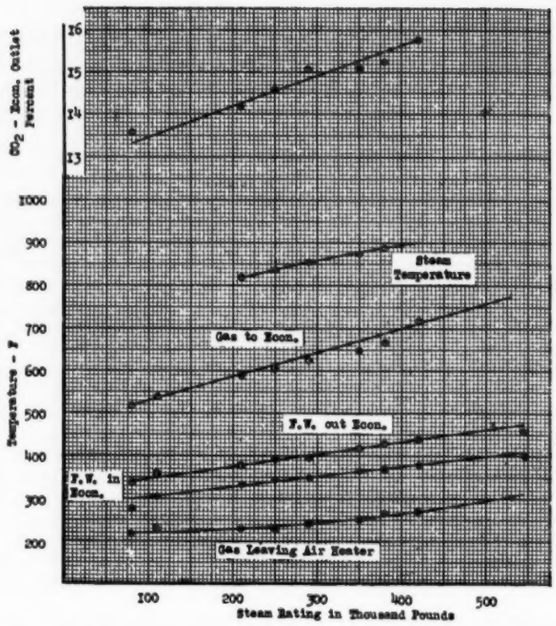


Fig. 6—Chart showing gas analyses and temperatures

and starting buttons for all boiler-feed pumps are installed on the boiler gage board, so that the boiler operator has control of these very essential auxiliaries if occasion demands.

Of particular interest is the handling of slag, the arrangement of which is shown on Fig. 5. The installation consists of a hopper-shaped slag pit under the boiler into which the slag drips continuously from the furnace. Under this pit is a combination grinder and feeder and below this a sump from which the slag pumps take their suction. Sluicing pumps have been eliminated entirely.

The equipment is operated by pushing a "start" button on the ash-control board which, in turn, starts the ash-removal pumps and feeder. After an elapse of about 30 sec the gate under the slag hopper opens automatically. Proper water level in the pits is controlled by automatic float valves. Pushing the "stop" button on the equipment closes the slag gate and, after a 30-sec interval, stops the feeder and ash pump.

Practically no supervision of the operation of this equipment is required except for starting and stopping. The feeder prevents any overfeeding of slag and also crushes all lumps to a size that can be handled by the ash pump. The dangers of plugged slag-sluice lines, due to either of these causes, is therefore eliminated.

Turbine-Generator Unit

The turbine-generator is rated at 50,000 kw, 85 per cent power factor, is air-cooled and operates at 1800 rpm. Use of a 3600-rpm machine was considered and there was some gain in economy with the higher-speed machine, but this was offset partially by higher fixed charges; and since operating experience was highly satisfactory with the existing machines, it was decided not to change. It should be noted, too, that 40,000 kw was the largest size 3600 rpm condensing unit available at the time. Space was not a factor, as the existing turbine column spacing would accommodate the 50,000-kw, 1800-rpm machine without difficulty.

Hydrogen cooling on the generator was also available but at 1800 rpm the economy of this method of cooling did not justify the increased cost and complication.

The turbine is a 17-stage unit of the single-cylinder, impulse type. All seventeen stages are enclosed in a cast-steel casing made in two pieces split on the horizontal center line. The valve casings, both top and bottom, are integral with the shells. This method of construction has eliminated two joints that have been some source of maintenance—one at the valve chest, and the other a four-way joint at the junction of the high- and low-pressure casings. Glass-wool blankets for casing insulation and stellite shields on the last row of turbine blades have also been provided.

The auxiliary oil pump is motor-driven and an ac-dc drive has been provided for the turning-gear oil pump. In event of an extreme emergency and loss of all a-c power, the tubine could be brought to rest by using the turning gear oil pump for lubrication, this pump being driven by a d-c motor from the station storage battery.

The condenser is a single-pass unit, vertically divided on the water side. Two circulating water pumps are used, one for each side; so that half the condenser can be cut out at any time by merely shutting down one pump. The condenser has a built-in reheating and deaerating hotwell. Float controls bypass sufficient water from the condensate pump discharge back to the hotwell to protect the pump at all light load conditions.

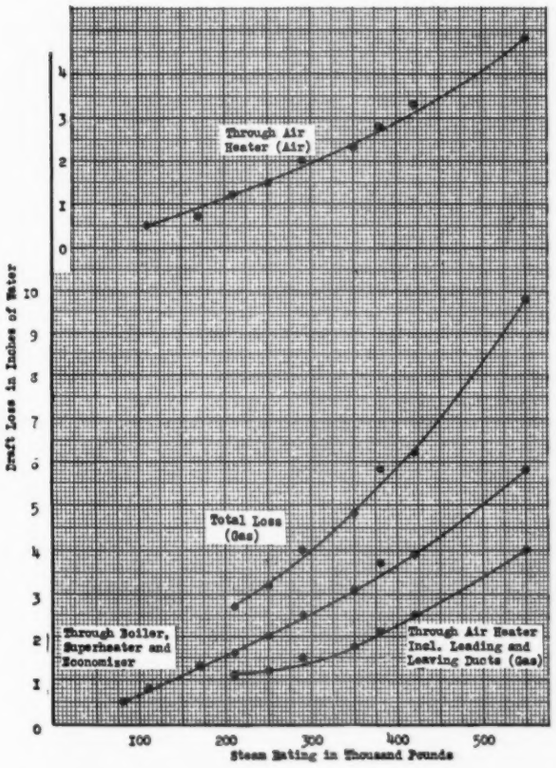


Fig. 7—Draft loss at different ratings

Coal-Handling Equipment

As the present equipment on order for Buzzard Point will result in a station of 170,000 kw by 1942 with an estimated capacity factor of 80 per cent, it was decided to design the new coal-handling equipment for the ultimate station capacity of 270,000 kw immediately. The final layout included a rotary car dumper for unloading, a Bradford breaker and belt conveyors from the point of unloading to the station bunkers, of 500 tons per hour capacity. A single 500-ton, 42-in. belt carries the coal from the unloading point on the west side of First Street to a junction point behind the station on the east side of the street. Two 30-in. belts carry the coal from this junction to the bunkers.

Particular attention has been given to elimination of dust nuisance and the possibility of dust explosion. The car dumper is located in a tight enclosure with sliding doors. Fans have been provided for pulling the dust and air from this unloading house and also from each belt conveyor junction point, and the top of the bunkers themselves. These fans deliver to suitable dust-separating apparatus and the caught dust is remixed with the incoming coal.

Preliminary Operating Results

The machine was first synchronized on October 16, 1940, and was up to full load on October 17. Since then the unit has been off the line only for week-end shutdowns for minor adjustments and changes. Under test conditions the boiler unit was brought up to 550,000 lb of steam per hour for a half-hour period.

The following data should not be considered as final due to the impossibility of having all metering equipment accurately calibrated during the first weeks of operation. However, it is indicative of the approximate efficiency of the new unit. The period covered was from November 1 to 15, 1940, inclusive.

Total gross kwh generated	17,262,000
Total kwh station uses	762,800
Total net kwh output	16,499,200
Station service, per cent of gross	4.40
Water fed to boilers	144,400,000
Pressure and total steam temperature	690 lb g. 892 F
Temperature of feedwater entering economizer	381
Net Btu per lb of steam	1,100
Steaming coal, lb	12,500,000
Btu per lb of coal as fired	14,392
Circulating water temperature	56
Hours operation	360
Capacity factor	95.9
Station water rate, lb per kwh	8.4
Boiler steaming efficiency	88.0
Average boiler output, lb per hr	401,000
Boiler use factor, per cent	100
Hours steaming	360
Hours on bank	0
Hours on repair	0
Lb of coal per kwh net*	0.76
Btu per kwh gross	10,450
Btu per kwh net	10,930
Thermal efficiency, per cent	31.2

* Includes coal equivalent of oil burned.

Of additional interest, in connection with preliminary operating data, are Figs. 6 and 7. These graphs show the variation, with rating, of gas analysis, temperatures and draft loss.

In general, the results up to the present time indicate a very satisfactory operating unit.

Partial List of Equipment
1940 Addition—Buzzard Point Station

Boiler

Three-drum, bent-tube type with C. E. water-cooled furnace and bifurcated water wall tubes; 525,000 lb per hr evaporation; design pressure 775 lb per sq in. in boiler drum.

Operating conditions, 735 lb in boiler drum, 690 lb, 900 F at superheater outlet with feedwater at 395 F. Heating surface—17,150 sq ft.—*Combustion Engineering Company, Inc.*

Soot Blowers furnished by *Diamond Power Specialty Corp.*

Superheater

"Elesco" type with two-pass elements to raise temperature of steam to 900 F at a pressure of 690 lb per sq in. at all ratings from 325,000 lb to 525,000 lb per hr. Heating surface, 14,800 sq ft. Elements of chrome molybdenum, carbon molybdenum and low carbon steel, depending on temperature.—*Combustion Engineering Company, Inc.*

Economizer

"Elesco" split type, fin tube, continuous loop; heating surface, 13,780 sq ft.—*Combustion Engineering Company, Inc.*

Air Preheaters

Two Ljungstrom regenerative type; heating surface, 25,800 sq ft each.—*The Air Preheater Corporation.*

Pulverizers and Exhausters

Three Atrita duplex pulverizers with integral exhausters; capacity, 20,000 lb per hr with eastern bituminous coal; grindability 80, moisture 7.5 per cent; 27,000 lb per hr, grindability 100, moisture 3.5 per cent.—*Riley Stoker Corporation.*

Drive—250-hp, 3-phase, 2300-volt, 900-rpm induction motors.—*Allis-Chalmers Mfg. Company.*

Fans—Induced Draft

Two "Sirocco" fans each having a capacity of 152,000 cfm at 350 F against a static pressure of 15.2 in. w.g. when running at 860 rpm. Hydraulic coupling speed control.—*American Blower Company.*

Drive—500-hp, 3-phase, 2300-volt, 900-rpm induction motors.—*Allis-Chalmers Mfg. Company.*

Fans—Forced Draft

Two Type HS fans each having a capacity of 78,750 cfm at 100 F against a static pressure of 9.4 in. w.g. when running at 1170 rpm; vane control.—*American Blower Company.*

Drive—150-hp, 3-phase, 2300-volt, 1200-rpm induction motors.—*Allis-Chalmers Mfg. Company.*

Precipitator

Cottrell electrical precipitation equipment; three units in parallel and three units long.—*Research Corporation.*

Turbine-Generator

One 50,000-kw, 85 per cent p.f. (58,824 kva), 1800-rpm, air-cooled generator 13,800 volts, 3-phase, 60-cycle, with direct connected exciter and pilot exciter.

Horizontal condensing, 17-stage turbine consisting of a single horizontal unit of the impulse type. Design conditions are 650 lb per sq in., 900 F total temperature at the throttle, 1 in. hg abs pressure at exhaust hood.—*General Electric Company.*

Condenser

Horizontal, single-pass surface condenser, split vertically on water side; Admiralty tubes; cooling surface, 41,000 sq ft.

Duplicate sets of steam-air ejector equipment.

Maximum capacity of condenser, 375,000 lb per hr.—*Worthington Pump & Machinery Corporation.*

Circulating Pumps

Two double-suction volute pumps each designed to deliver 37,000 gpm against a total dynamic operating head of 19.44 ft.—*Worthington Pump & Machinery Corporation.*

Drive—250-hp, 3-phase, 60-cycle, 2300-volt, 300-rpm induction motors.—*Allis-Chalmers Mfg. Company.*

Condensate Pumps

Two three-stage hotwell pumps designed to handle 800 gpm against a total dynamic head of 134 ft.—*Worthington Pump & Machinery Corporation.*

Drive—60-hp, 3-phase, 2300-volt, 900-rpm induction motors.—*Allis-Chalmers Mfg. Company.*

Boiler-Feed Pumps

Three 7-stage, horizontally-split, high-pressure boiler-feed pumps designed to deliver 575,000 lb per hr of water at 334 F against a total head of 2025 ft.—*Ingersoll-Rand Company.*

Drive—Two 800-hp, 3-phase, 60-cycle, 2300-volt, 1800-rpm wound-rotor motors.—*Westinghouse Electric & Mfg. Company.* One 900-hp quick-starting turbine, 650 lb, 900 F at throttle, exhausting to atmosphere.—*Terry Turbine Company.*

14th-Stage Heater

One counter-current, rain-type, spray heater, vertical cylindrical shell with vent condenser, 84 in. O.D., 50 lb per sq in. gage working pressure. 1100-gal storage at bottom of heater shell.—*Foster Wheeler Corporation.*

11th-Stage Heater

Same as for 14th-stage heater.

8th-Stage Heater

Same as for 14th-stage heater except 125 lb per sq in. working pressure, Class I construction. No water storage.

Boiler-Feed Tank

84-in. I.D., Armco iron, 37 ft 3 in. over heads, Class I construction. Capacity, 7400 gal when water level two-thirds to top of tank.—*Foster Wheeler Corporation.*

5th-Stage Heater

Vertical, high-pressure, removable bundle, floating head, 4-pass, closed heater. Terminal difference, 3 deg F above saturation; 1853 sq ft.—*Foster Wheeler Corporation.*

Evaporator and Evaporator Condenser

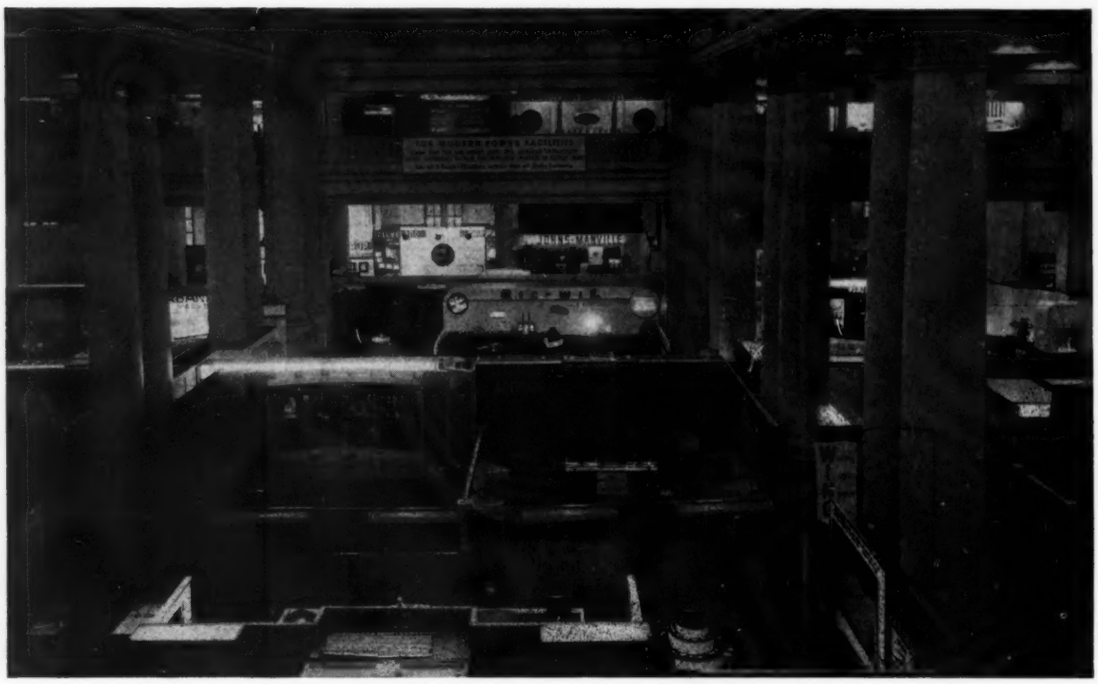
Horizontal, submerged "H" coil-type evaporator with integral tray-type degasifying preheater. Coil surface, 534 sq ft, 72-in. shell, 17 ft long. Maximum capacity, 10,000 lb vapor per hr. Working pressure, 125 lb per sq in. Vertical removable bundle floating head, 2-pass condenser, 502 sq ft.—*Foster Wheeler Corporation.*

Coal Conveyors

Capacity, 500 tons per hr. One 42-in. belt unloader under First Street to rear of station; two 30-in. belts from junction of new and old coal-handling equipment to station bunkers.—*Robins Conveying Belt Company.*

Rotary Car Dumper

Semi-automatic rotary car dumper to handle coal cars up to 70 tons capacity at the rate of 25 per hr.—*Link-Belt Company.*



One view of the Fourteenth National Power Show at New York, December 2 to 7

It displayed the products of 306 exhibitors and was attended by approximately 37,000 people

A.S.M.E ANNUAL MEETING

THIS year's Annual Meeting of the American Society of Mechanical Engineers, with a total registration of nearly 2500 was held at the Hotel Astor, New York, December 2 to 6. The program included forty-five technical sessions of which a substantial number dealt directly or indirectly with the production of power. Among these were papers on silica removal from feedwater, boiler design and circulation, furnaces, boiler casings, stoker fuel beds, fluid temperature of ash, steam piping, condenser tubes, flue dust recovery, turbine lubrication and marine power plants. Digests of some of these papers and their discussions follow:

Methods of Silica Removal

Removal of silica from boiler waters formed the subject of three papers at the Monday evening session on "Boiler Feedwater Studies."

Harold Farmer, Chief Chemist of the Philadelphia Electric Company, in a paper on "Silica in High-Pressure Boiler Waters," observed that, in general, silica had not given serious trouble at steam pressures below 600 lb, or else could be effectively controlled. However, with high steam pressures around 1200 lb, and particularly with high rates of heat input, there have been many tube failures in which silica appears to have played a significant part.

It has been suggested that in some cases high rates of evaporation have disturbed the circulation and resulted in starvation in certain tubes, thus permitting deposition of soluble salts, including silica, on the dry areas. When these areas are again wetted the soluble salts are dissolved, but during the dry period the silica may have undergone a change in structure and ceased to be soluble. With repetition of such cycles the silica deposit will build up and cause overheating of the tube with resulting ultimate failure. Some such failures have been manifested by blistering.

In other cases, instead of a blister, a small hole surrounded by hard silica scale has been noted. Some have attributed this type of failure primarily to starvation with accompanying silica deposits and ultimate failure due to small pieces of this scale breaking away and the exposed metal trying to absorb too much heat.

Even with good condensate feedwater, assuming the total solids to be 1 ppm, the water may contain 0.1 ppm of silica. While this may seem insignificant, many present-day high-pressure boilers evaporate their own volume of water five times in one hour, which represents 12 ppm of silica in the boiler at the end of 24 hr. Many operators set this figure as the limit and resort to blowing down when this figure is approached.

Plants operating with high makeup, not evaporated, have to resort to external chemical treatment for removal of silica. The present effectiveness of such treatment, in the author's opinion, appears to have a limitation of about 2 ppm of silica residual remaining in the water. This may necessitate continuous blowdown in order to maintain the silica in the boiler water under 12 ppm, but frequent blowing down of high-pressure boilers is not looked upon with favor by the operators.

The use of internal chemical treatment for silica has been given some consideration, but as yet has not proved very satisfactory, because of the necessity for very close supervision and control of several variables.

Finally, a knowledge of the combination and form in which silica occurs is most important as it throws light on the physical conditions which play a part in the formation of scale. While chemical analysis of boiler scale will show the total silica present, this may exist in as many as five different forms, all of which have different physical properties. However, the more recent employment of the X-ray diffraction method of analysis of scale has made it possible to identify compounds which from previous knowledge enables one to determine the temperature at which they could have been formed.

An Improved Magnesia Process

"Silica Removal by an Improved Magnesia Process" was the title of the second paper of the session, by **H. L. Tiger,** vice president of The Permutit Company. This process involves the combined use of ionic magnesium and sludges containing undissolved magnesium compounds in which a modified Spaulding Precipitator is employed to afford extended and intimate contact between the water and the sludge. This equipment permits the usual lime-soda reactions to take place at the same time as silica removal and, by the addition of a coagulant, simultaneous turbidity removal can be accomplished. The source of magnesium is low-cost dolomitic lime.

Summarizing the extensive research study of various means of silica removal, as detailed in the paper, the author offered the following conclusions:

(*a*) For any given set of conditions ionic magnesium precipitated as $Mg(OH)_2$ is most efficient, but undissolved magnesium compounds of proper quality (fine particle size, etc.) also give satisfactory results when favorable conditions of sludge concentration and agitation are maintained.

(*b*) The efficiency of removing silica by precipitating ionic magnesium or by undissolved magnesium compounds increases with temperature, but the application of other factors disclosed makes it possible to obtain satisfactory results at low temperatures. Slight pre-warming of the water to about 30 or 40 C (86 to 104 F) reduces the amount of magnesium required to obtain the desired result. Waste heat may be used for this purpose.

(*c*) The efficiency increases with the concentration of the magnesium-containing sludge in contact with the water.

(*d*) Increasing the time of contact with the sludge

absorbent in agitated suspension improves the results.

(*e*) Reducing the silica contamination of the retained concentrated sludge reduces the silica in the effluent. That is, if the magnesium added to the system is increased, the ratio of Mg to SiO_2 in the sludge rises correspondingly and the residual SiO_2 in the effluent decreases.

(*f*) The presence of phosphate ion interferes with silicon absorption by MgO.

(*g*) In those cases where additional magnesium is required for the desired silica reduction, it can usually be obtained most economically from dolomite lime [$Ca(OH)_2MgO$]; and where no lime is required in the treatment calcined magnesite (MgO) is used.

(*h*) Ionic magnesium may be added to the raw water economically without increasing the lime requirement or the total solids content of the effluent by recirculating sludge into a magnesium dissolver compartment, or low pH zone, where the HCO_3^- and CO_2 in the raw water dissolves Mg^{++} from this sludge. If necessary, additional CO_2 may be added by flue-gas carbonation to increase further the amount of Mg^{++} introduced.

In applying this process it may be stated, in general, that if hot-process lime-soda treatment is used to reduce the hardness, superior silica removal is obtained by employing equipment that provides positive agitation and intimate sludge contact, such as the Spaulding Precipitator. If hot-phosphate softening is employed, the silica removal treatment should precede the phosphate treatment. If a cold-process is employed, the silica removal is first applied and advantage may be taken of post-treatment by carbonaceous zeolites which completely eliminate residual hardness. Carbonaceous hydrogen zeolite treatment may also be included to reduce the final alkalinity to any predetermined figure.

Removal by Adsorption

The third paper of the session dealt with "Adsorption Process for Removal of Soluble Silica from Water," by **L. D. Betz, C. A. Noll** and **J. J. Maguire.** In this process removal of silica from solution is effected, not by chemical reaction, but by adsorption in which a specially prepared form of magnesium from sea-water bitterns, identified as "Remosil" is employed. It is well adapted for use in conjunction with hot-process lime-soda softening and requires no increase in the quantities of either lime or soda ash. While the pH range for best operation is not critical, the optimum pH is approximately 10.1

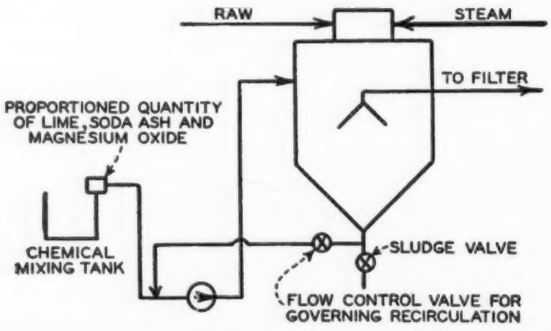


Fig. 1—Diagram showing recirculation of magnesium oxide sludge

The authors pointed out that although silica is conventionally expressed as SiO_2 in a water analysis, there is a marked distinction between crystalloidal and colloidal silica. The major portion of the silica found in natural waters is in the crystalloidal state. Silica suspended in water in the form of mud can be readily removed by coagulation and filtration and the major problem in the conditioning of boiler feedwater is the removal of soluble silica from solution. The adsorption process permits a reduction in soluble silica with a decrease in solids content of the treated water, rather than an increase.

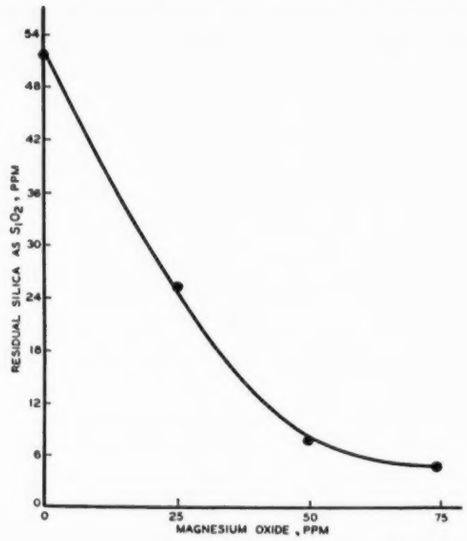


Fig. 2—Field test on silica removal with sludge recirculation

An important factor is the temperature at which silica removal is effected by means of magnesium oxide, the efficiency of removal increasing with temperature. The major increase in the percentage of silica removal occurs with an increase in temperature up to 95 C (203 F), the approximate temperature of operation of hot-process softeners. Furthermore, where the silica content of the raw water is to be reduced to 2 to 5 ppm little is to be gained by increasing the time of retention beyond one hour at 95 C. In fact, equilibrium is reached almost completely in about 15 min, in which time the silica removal is about 85 per cent complete, but in the cold a much longer time is required.

A characteristic of the adsorption process is the need for increased quantities of magnesium oxide to effect removal of the last 10 to 20 per cent of the original silica content. This does not mean that the higher the initial silica content, the less that will be removed per part of magnesium oxide; in fact, the reverse is true, but for any definite initial silica content in the raw water, as the amount removed from solution increases with increase in quantities of magnesium oxide, the silica removed per part of magnesium decreases. Advantage is taken of this characteristic by employing the partially spent magnesium, through recirculation of the sludge, for partial silica removal and thus lessening the quantity of fresh magnesium oxide to reduce the final percentages of silica.

By recirculation it is actually possible to increase the silica removed per part of magnesium oxide with increasing removal of silica from solution.

The sketch, Fig. 1, illustrates the application of sludge recirculation with a lime-and-soda softener and the curve in Fig. 2 represents silica removal accomplished in a hot-process lime-soda softener with three different rates of feed of magnesium oxide, of 25, 50 and 75 ppm. In these field tests the magnesium oxide was added to the chemical mixing tank along with the lime and soda ash and recirculation of the sludge was effected as shown in Fig. 1.

Treatment of Makeup at Waterside Stations

At the second Boiler Feedwater Session, Messrs. **Arnold, Hanlon** and **Mindheim** of the Consolidated Edison Company of New York, Inc., presented a paper on "Treatment of Makeup Water for the Waterside Topping Installation."

This high-pressure installation at present consists of two 50,000-kw turbine-generators supplied by four 1400-lb boilers and exhausting at 200 lb to the existing low-pressure system. Two more high-pressure turbines and four more high-pressure boilers, capable of supplying 2,460,000 lb of steam per hour are now under construction. The 200-lb system serves the dual purpose of supplying the low-pressure condensing turbines and supplying steam to the heating mains of the New York Steam Company through twelve desuperheaters having a total capacity of about 1,250,000 lb of steam per hour. Although all the low-pressure boilers have been removed from Waterside Station No. 2, the 200-lb system may still be fed by steam from the old low-pressure boilers in Waterside No. 1 which are capable of supplying 1,836,000 lb per hr.

Condensate from the low-pressure turbines and auxiliaries is used for feedwater and at first it was deemed advisable to evaporate makeup for the high-pressure boilers in the low-pressure boilers, but this obviously was not most economical. Consequently, it was decided to treat the makeup which is Croton water from the city mains. On the basis of thermal economy, degasification, treating costs and installation convenience, a cold-water carbonaceous zeolite (Zeo Karb) system was selected as best suited to the hardness characteristics of Croton water. Three sodium and three hydrogen units were installed and special regulating equipment was provided to proportion properly the water treated by these two types of units. Each pair of units is capable of handling 600,000 lb of water per hour and all or any combination of pairs of units may be employed for treating. A degasifier is provided to remove carbon dioxide from the water after the mixing of the effluents from the sodium and hydrogen units.

Although the Zeo Karb system removes most of the hardness from the feedwater, additional chemical treatment is employed. This includes sodium hydroxide fed into the feedwater line at the deaerator outlet in sufficient quantity to maintain a pH of 8.8 in the feedwater passing through the economizers, and disodium phosphate which is fed directly into the boiler drums; this in addition to a continuous blowdown system to maintain the boiler water concentration sufficiently low to prevent carryover.

The following table is indicative of the performance of the water-treating system at Waterside No. 2:

PERFORMANCE OF ZEO KARB UNITS

Chemical Concentration Expressed as ppm	Raw Water Croton Supply	Sodium Zeolite Unit Effluent	Hydrogen Zeolite Unit Effluent	Mixed Effluent of Degasifier Outlet (1)
*Total hardness as $CaCO_3$	45	0	0	0
Calcium hardness as $CaCO_3$	30	0	0	0
Magnesium hardness as $CaCO_3$	15	0	0	0
M.O. alkalinity as $CaCO_3$	34	29	−16**	4
Sodium alkalinity as Na_2CO_3	0	0	0	0
Free carbon dioxide, CO_2	3	3	30	2
Chloride as NaCl	7	7	7	7
Sulphate as Na_2SO_4	18	18	18	18
Silica, SiO_2	6	6	6	6
Total solids	65	60	31	35
pH	7.2	7.0	3.7	6.3

(1) Ratio of hydrogen to sodium effluent 56–44.

* American Public Health Association soap test.
** Free Mineral acidity expressed as minus alkalinity.

It has been found that high hydroxide concentration leads to foaming and to fouling of the turbine blading and the following limits have been prescribed for the high-pressure boiler water composition:

	Ppm Max	Min
Phosphate Na_2PO_4	25	15
Sodium hydroxide NaOH	30	20
Sodium chloride NaCl	150	
Sodium sulphate Na_2SO_4	250	
Total dissolved solids	450	

Conductivity Determinations

A new degasifying steam condenser for use in conductivity determinations was described by Prof. **F. G. Straub** and **E. E. Nelson,** both of the University of Illinois.

This condenser is designed to furnish a continuous sample of either steam or condensate that is free from dissolved gases but which contains the dissolved solids present in the original sample. The apparatus, which is shown in Fig. 3, makes use of the principle of boiling a sample of the condensed steam from which the gases have been removed to furnish a gas-free steam that, in turn, removes the gases from the condensed steam. In order to obtain efficient removal of the gases, a scrubbing tower or stripping column is employed in connection with a vent condenser, so as to allow venting of the gases after being removed from the condensed steam.

The degasifying condenser may be used for sampling steam or condensate. When used for the former, the steam to be sampled is throttled to allow 60 to 70 lb per hr to flow to the unit. The steam enters through metal tubing *a* to the heating or reboiling coil *b* where the major portion of the available heat is removed. The partially condensed steam then passes to the condensing coil *c* where it is completely condensed and cooled. The condensed and cooled steam sample now passes through valve *d* which is opened wide, while valve *e* is kept closed. The sample passes up and part of it overflows to waste *f*, or to a conductivity cell if the conductivity of the undegasified sample is desired. A portion of the condensed sample flows through an orifice *g* and through a preheating coil *h* where it discharges onto the top of plates *i*. The flow is constant and the sample is representative of the condensed steam, since it has been condensed and cooled prior to passing through the orifice. It contains all the dissolved solids present in the steam along with the dissolved gases.

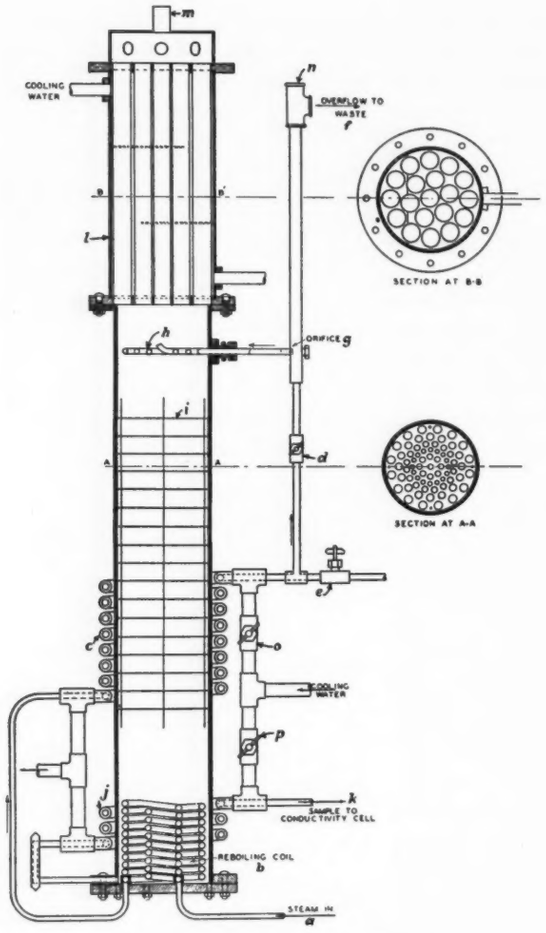


Fig. 3—Degasifying steam condenser

The dissolved gases are removed by passing the sample down through the scrubbing or stripping column which is made up of a series of plates which give very low pressure drop. This gas-free sample then falls to the bottom reservoir or reboiling chamber. The heat from the steam passing through coil *b* boils the gas-free water and thus furnishes gas-free steam which passes up through the column and removes gas from the sample flowing down.

The gas-free sample in the reservoir flows out through a cooling coil *j* and then at the proper temperature is available to flow to a conductivity cell *k*. The conductivity of the sample gives a measure of the dissolved solids directly without correcting for dissolved gases.

Steam, after passing up through the column, is condensed in the top vent-type condenser *l* where the gases pass out the top *m* and the condensed steam drops back on the top plate. The condenser is so operated that no appreciable amount of steam is allowed to be lost through the vent.

Coal-Ash Fusing Temperature

The results of investigations on ash-fusing temperatures were reported in a paper by **E. G. Bailey,** vice president of Babcock & Wilcox Co. and **F. G. Ely** of that company. These studies confirmed the earlier work of Fieldner, Nicholls and others in showing that the form of the iron, whether ferrous or ferric, is of increasing importance with increased iron content, but also carried these indications further as applied to the modern high-duty pulverized coal furnace.

Granting that the softening temperature of the ash in a reducing atmosphere, as prescribed by the A.S.T.M. method, is applicable to stoker fuel beds, the authors pointed out that with pulverized-coal firing it is the fluid temperature that is most important. Their studies indicated the iron content of the ash as the determining factor in this respect. In the first part of a slagging-bottom furnace the atmosphere is largely reducing and the iron, which initially is mostly in the pyritic form, first gets rid of its sulphur and then becomes oxidized to FeO, thereby imparting a low fluid temperature to the ash. On the other hand, much of the ash deposited on the upper furnace walls and boiler surfaces is brought there in company with unconsumed coke which burns slowly and in an oxidizing atmosphere. Hence, the iron in the ash at these locations is largely in the Fe_2O_3 state with a fluid temperature some 200 deg higher than that formed in the reducing atmosphere in the first part of the furnace.

This fact seemed to explain why, in certain cases, coals with relatively low ash-fusing temperature have given less trouble from slagging of heating surfaces than had been anticipated; also, why some such coals have been burned satisfactorily in dry-bottom furnaces where ample water-cooled surface was provided to keep the ash below its troublesome temperature.

Measurements, by means of a water-cooled probe, to determine the effect of slag on the rate of heat absorption, showed that a state of equilibrium was reached in about three hours with a slag film $^1/_8$ in. thick and the molten slag dripping off as fast as additional ash collected. Under these conditions the rate of heat absorption decreased to about 50 per cent of the original. It is this state of equilibrium, representing operating conditions, for which a unit must be designed.

It was observed that slag can be tapped more easily when operating with low excess air which produces a more fluid slag because of the ferrous condition of the iron. Pyrites in free pieces when properly pulverized and burned will result in the formation of Fe_2O_3, Fe_3O_4 and FeO, depending upon the degree of oxidizing atmosphere present. But, if the particles are too coarse for partial or complete oxidation, FeS may be formed and this is very troublesome. Furthermore, excess carbon, resulting from coarse unburned coal on slag surfaces, may reduce any form of iron oxide to metallic iron which will settle to the bottom of the molten slag pool and form salamanders which are difficult to remove.

The slag collected in the first part of the furnace is materially higher in iron content than that of the original coal ash, due to the pyrites in the coal being coarser and heavier and thereby falling to the bottom; whereas the ash collected in the boiler-tube bank has about the same iron content as that of the original coal.

In the discussion of the paper, the opinion was advanced that magnesium and lime may have a more important influence on fluid temperature with certain coals than iron; also, that the time element may be a considerable factor in the more complete oxidation of the iron in the slag on the boiler surfaces. While conceding that magnesium and lime content were factors, Mr. Bailey reiterated his opinion that these were secondary to the iron.

An Unique Engine and Boiler Unit

A new type of steam engine and forced-circulation boiler, designed by **S. L. G. Knox** of Engelwood, N. J., and tested at Stevens Institute by Professor **J. I. Yellott,** was the subject of a joint paper by these authors.

The engine is of the high-speed compound uniflow type designed to operate at 700 lb pressure 750 F and deliver 90 hp at 1000 rpm. The inlet valves are of the piston type and the direction of rotation is reversed by changing the direction of flow of the steam through using one set of ports in the valves as steam admission ports when running in one direction and as exhaust ports in the other direction. The main exhaust from all three cylinders is through the uniflow ports with the piston valves handling the auxiliary exhaust necessary to keep compression down to a reasonable amount.

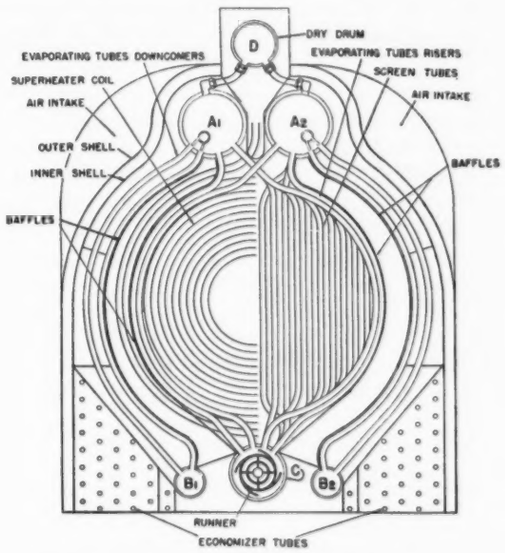


Fig. 4—Sectional elevation of Knox boiler

Although the present engine runs noncondensing it may be arranged to exhaust to a condenser and thus provide additional power. On test a steam consumption of 14.6 lb per bhp-hr (noncondensing) and an engine efficiency of 53.3 per cent was obtained at 75 per cent rated load.

Special interest attaches to the boiler which is light and compact and employs a new principle for obtaining forced circulation by placing an impeller in the lower drum. The present unit has a capacity of 1500 lb of steam per hour at 700 lb pressure 750 F total steam temperature and high combustion rates up to 400,000 Btu per cu ft per hr of furnace volume were obtained on test.

Referring to Fig. 4, which represents a cross-section of the boiler, feedwater enters the two drums A_1 and A_2 after passing through the economizers, two of which are shown in the last pass, the third being located in the duct leading to the stack. The usefulness of this last economizer was demonstrated on test which showed that the flue gas temperature entering the duct was about 590 F at full load, while the gas temperature at the last economizer outlet was 380 F. Leading down from the two upper drums are the downcomers, located in the third pass and connecting to the two outside lower drums B_1 and B_2. The center bottom drum C connects with drums B_1 and B_2 through headers at both ends, and within this center drum is a hollow impeller driven by a shaft which emerges from the header through a stuffing box. When the impeller is rotated, the pumping action creates a pressure that forces the water in drum C to pass upward through the risers which form the walls of the combustion chamber. Inasmuch as the impeller extends the length of the drum, circulation within the risers is quite uniform. The risers consist of four rows of $^1/_2$-in. O. D. stainless-steel tubes staggered on $1^3/_{16}$-in. centers.

As shown in the plan, Fig. 5, firing is by oil burners at one end and the gases have three passes. At the far end of the furnace is located the superheater which consists of a spiral coil of tubing, and steam temperature control is effected by injecting feedwater into the inlet of the superheater. Although the furnace is water-cooled it was found necessary to place refractory over the first few rows of tubes near the burners to provide radiant heat to assist in vaporizing the oil and to obtain smokeless combustion.

Beyond the rear wall is located the forced-draft fan which forces air through the space between the inner and outer shells of the boiler where it is preheated to about 350 F before entering the combustion chamber.

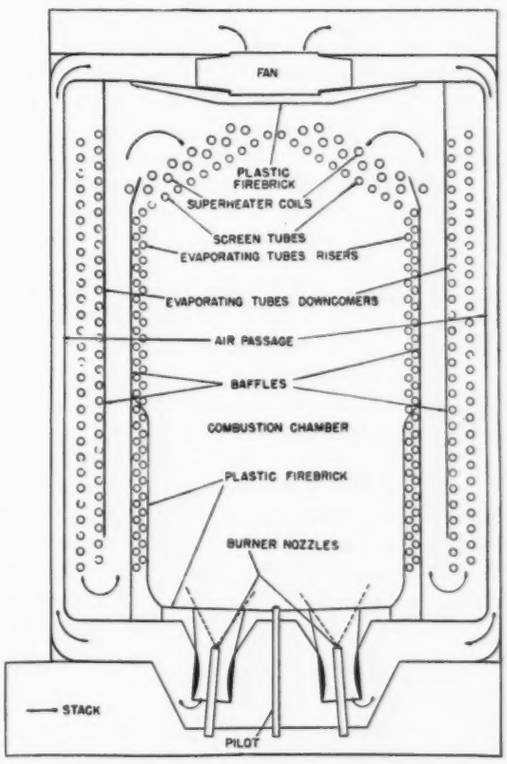


Fig. 5—Plan of Knox boiler

Control of the boiler operation is simplified by the relatively large water capacity of the upper and lower drums, which means that the fuel and water supplies do not have to be instantaneously adjusted. All controls are electrically operated. The pressure control consists of a spring-loaded bellows equipped with contacts connected in series with the solenoid valve in the oil line, and the high- and low-water level controls are of the thermal-expanding type provided with electrical contacts communicating with the fuel supply.

Test Data for Boiler

Duration of test	2½ hr
Rate of steam generation	1180 lb per hr
Evaporation per lb of oil	254 lb
Average steam pressure	515 lb
Average steam temperature	755 F
Temperature of feedwater	71 F
Heating value of oil	19,400 Btu per lb
Average CO_2 in flue gas	12 per cent
Flue gas temperature	380 F
Loss to flue gas	13.6 per cent
Loss due to incomplete combustion and unaccounted for	5.1 per cent
Efficiency (exclusive of auxiliary power)	81.3 per cent

In this test the boiler was started from cold and the steam pressure reached 500 lb and the steam temperature 700 F within 4 min.

Fuel-Bed Observations on Multiple-Retort Stoker

The second Fuels Session comprised two papers, one on "Continuous Heat Balance Control of Boiler Room Operation" by **B. S. Murphy,** and the other on "Flow Processes in Underfeed Stokers," by **Martin A. Mayers,** of the Coal Research Laboratory, Carnegie Institute of Technology.

The first of these papers, dealt with the procedure employed in scheduling boiler operation, loading, coal measurements and testing, and the functioning of the various control devices at the Hudson Avenue Station of the Brooklyn Edison. The author, who is chief engineer of this station, reviewed the many different factors entering into boiler operation and control, and showed how these factors must be synchronized before any comprehensive plan could be formulated.

In the second paper Mr. Mayers dealt primarily with the fuel-bed structure on a multiple-retort underfeed stoker, the flow of air and gas through the fuel bed, the flow of coal and the heat flow, as based on studies and measurements made under operating conditions.

Fig. 6 represents a cross-section through the fuel bed near the middle of such a stoker. The high temperatures generated in the burning lanes above the tuyères cause the formation of shrinkage cracks in the coke walls so that the agitation of the bed breaks off portions of the carbonized walls and the particles fall into the burning lanes, through which the greater portion of the air flows. Sections at different longitudinal positions differ from that shown, only quantitatively but not in kind, the coke walls being thinner at the head of the stoker and thicker at the end.

During the passage of the main primary-air stream through the bed of broken coke its oxygen content usually drops nearly to zero at distances of 3 to 5 in. above the tuyères. If the bed in the lane is much deeper than that, considerable carbon monoxide may appear in the gases leaving the lane. However, if there are places within the lane where the coke bed has not been replenished at the proper rate, unconsumed oxygen may pass through and up into the furnace. In general, the oxygen concentration at any level may vary within wide limits, depending upon the stream velocity, where the sample is taken, and the proximity of the coke surfaces.

A small portion of the air stream passes under the coke wall which defines the burning lane and into the retort where it passes through at low velocity due to the high resistance offered by the densely packed small coal. Part of this air may return to the main stream near the top of the burning lane or directly into the furnace. In either case it carries the tar vapor and gases released by the coal being carbonized.

At the higher levels in the retort, the carbon dioxide and monoxide also increase, while the oxygen decreases, until the skin of the coke at the top of the retort is penetrated, when, in many cases the oxygen concentration again increases while the combustible constituents tend to disappear. This indicates that there may be a layer of comparatively cold stagnant air lying on top of the retorts, which is only slowly aspirated into the main gas stream rising from the burning lanes.

The flow of coal takes place almost entirely in the retorts and in the walls of the burning lanes, there being practically no motion lengthwise or crosswise in the burning lanes. This was shown by the fact that porcelain probes inserted into the burning lanes could remain in position almost indefinitely. Coal which enters the retort near its top rises close to the front wall and is delivered to the burning lane at the head end of the stoker, whereas that which enters at the bottom of the retort passes well down the stoker before being delivered to the burning lane or part may be forced out onto the overfeed section without having reached the burning lanes.

A second function of the retort is to coke the green coal and prepare it for smokeless burning above the tuyère

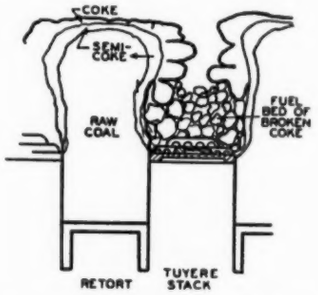


Fig. 6—Cross-section through fuel bed

stacks. This process takes place because the retort produces a transverse component of flow of the coal which has risen above the level of the tuyères, causing it to flow toward and through the coke walls. In this passage the coal is carbonized and is delivered to the burning lane as coke.

Proposed Heavy-Duty Stoker

On the basis of the observations made, Mr. Mayers outlined features that would be desirable in a stoker designed for much higher duty than any now in existence. In the first place, such a stoker would have narrower retorts than those of existing stokers which would make possible the preparation and coking of coal at higher rates. This would permit deeper fuel beds over the tuyères of the same width as now used and thus raise the ratio of active surface to the total area.

It is probably essential that the functions of distribution, coking and delivery, now combined in the retort flow, be separated so that the coke supplied to the tuyères will be as nearly uniform as possible. There should also be sufficient agitation, in this separating function, to

eliminate the possibility that coke walls may expand and constrict the burning lane.

Furthermore, it is suggested that such a stoker be supplied with a pulsating air blast the maximum rate of which would be sufficient to produce a condition close to that corresponding to instability of the bed. Under such conditions the fuel bed would be fluid enough to flow over any incipient blowholes and would allow ash liberated by combustion to sink through it to a cool zone at the bottom.

Finally, since it is desirable, by the use of a deep fuel bed, to require the air injected beneath such a stoker to take up as large a weight of the solid fuel, in the form of combustion gases, as it will carry and also, since operation at air-flow rates close to full teeter will cause a portion of the dust to be carried off the bed, it would be necessary to supply a large portion of the combustion air as overfire air.

Circulation in High-Pressure Boilers and Water-Cooled Furnaces

John Van Brunt, vice president of Combustion Engineering Company, analyzed the problem of natural circulation in high-pressure boilers. Starting with a simple U-tube circuit, he traced for various arrangements of circuits the conditions of stabilized circulation in which the head in the downcomers equals that in the risers plus all losses.

Inasmuch as the static head available to overcome all resistances depends upon the density of fluid in the risers and downcomers, any analysis of circulation must begin with determination of the density. This must be based on the correct rate of heat absorption by the exposed surface in the circuit being analyzed. Curves were shown representing the mean density of steam-water mixtures at 1350 lb per sq in., the changes of density along the tube, and the effect of density calculating methods on available static head.

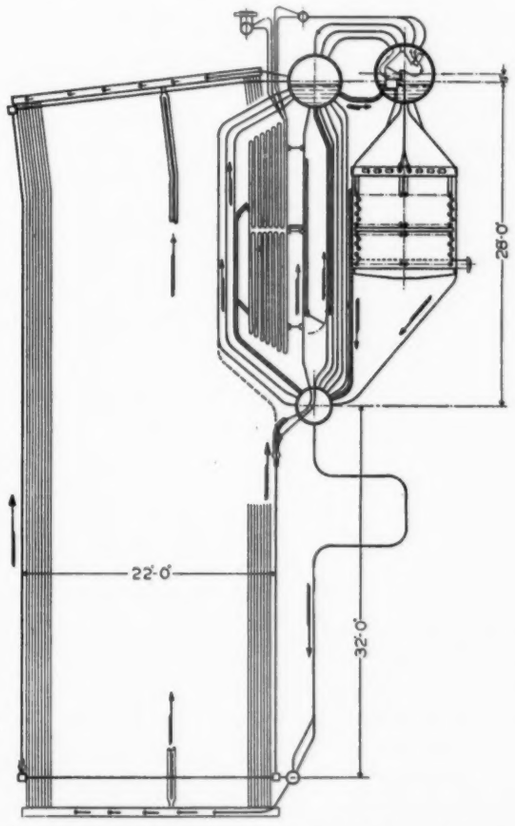


Fig. 7—Indicating circulation in typical three-drum steam generating unit of 650,000 lb per hr capacity at 1350 lb pressure and 925 F total steam temperature

Selecting a typical three-drum unit of 650,000 lb per hr capacity to operate at 1350 lb pressure and 925 F total steam temperature with feedwater of 470 F, the author traced through the necessary calculations for proportioning the furnace and walls, based on the values given in the curves. The same method was applied in calculating the front bank of boiler tubes.

Conclusions arrived at as a result of the analysis were that circulation in high-pressure units of the type illustrated in Fig. 7 is adequate for maximum load conditions and with a comfortable margin for substantial overloads. If the height of furnace is decreased, the available head and friction losses in the downcomers and risers also decrease, but losses in the horizontal members are unchanged; hence there is a lower limit of height below which the circulation would be progressively less until the top dryness fraction approaches unity. Under these conditions the evaporating tubes would be likely to fail from overheating. Therefore, under certain conditions with high-capacity, high-pressure units of low height, natural circulation may become inadequate.

Discussion

It was pointed out by several discussers that analyses, such as contained in Mr. Van Brunt's paper, are quite necessary in order to avoid difficulties incident to some of the earlier high-pressure installations, providing such analyses are tempered by field data; for average conditions seldom obtain in actual operation. That is, not only does the cleanliness of heat-absorbing surfaces vary but the dryness factor will not be uniform in different tubes because of their locations; also, it is difficult to determine entrance and leaving losses because of turbulence and varying velocities. It was suggested further that if the specific volume of the steam in certain tubes increases faster than that in others a condition of unbalance will be set up.

Some differences of opinion were expressed as to whether the limit was being approached for natural circulation, beyond which forced circulation would be necessary. One view was that there remained much to be learned about natural circulation, which should be studied further before adopting forced circulation for large capacity units for very high pressures and that the high boiler rooms, usually necessary for such natural-circulation units, represent the most economical arrangement in certain localities. Reference was made to the very high heat inputs in Navy boilers employing natural circulation with limited height.

Twin Furnace Boilers

John Blizard and **A. C. Foster,** both of Foster Wheeler Corp., in a paper on "Some Particulars of Design and

Operation of Twin-Furnace Boilers," described and illustrated three designs falling within this class. These were:

1. A boiler with two furnaces, in only one of which is placed a radiant superheater and, in addition to the radiant superheater, there is a convection superheater over which the gases from both furnaces pass.

2. A boiler with two furnaces in only one of which there is a superheater of the radiant type, and the gases from which pass through the furnace with no superheater. This type is adapted to marine installations and if a separate supply of saturated steam is desired, this may be taken directly from the steam drum.

3. A boiler with two furnaces from both of which the gases pass over a convection superheater, there being no superheater of the radiant type.

With such boilers, it was explained, it is possible to increase the water-wall surface surrounding the furnaces and, by differential firing, to control the steam temperature over a wide range of load without the necessity of providing a large convection superheater. Performance curves of several such boilers were included to show the flat superheat curve attained with differential firing.

In answer to a question from the floor as to what would happen with such a boiler employing a slagging bottom furnace if the load were suddenly lost, Mr. Blizard explained that this design is essentially a dry-bottom unit.

Boiler Settings

The importance of the setting enclosure of a furnace, boiler and heat-recovery equipment was discussed by **Max H. Kuhner,** Chief Engineer of Riley Stoker Corporation in a paper on "Steel Encased Settings for Modern Steam Generating Units."

If a setting becomes leaky after a few starting and stopping cycles, the boiler efficiency suffers, auxiliary power increases, capacity may be reduced, combustion control may be thrown out of adjustment and the boiler-room atmosphere contaminated with dust and gases. The necessity for constant maintenance on sealing joints and openings can occasion a costly expense item as well as large economic loss. After a few months of operation under these conditions, any savings made in the initial investment by the selection of a low-cost setting will have been absorbed many times by the losses chargeable to such a setting.

Experience indicates that a steel-encased setting constructed to withstand an internal pressure of 50 lb per sq ft in the furnace and 75 lb per sq ft in the gas passages between the furnace and the induced-draft fan, without deflection beyond ordinary limits, is remarkably immune to damage from the more common furnace and gas-pass explosions. With settings constructed to withstand furnace puffs and explosions of lesser magnitude, it was the author's opinion that explosion doors serve no practical purpose; for in most cases explosions occur in those locations from which the internal pressure wave created will reach the relief opening after the damage has been done.

In designing a steel-encased setting it is important to consider the movement of pressure parts of the steam generating unit. Expansion and contraction in tubes, drums and headers are considerable in large high-pressure units, hence it is important that the setting enclosure be free and independent.

Among the other minimum requirements for modern boiler settings, the author listed efficient heat insulation for low radiation loss and comfortable outside temperature, permanency not less than the life expectancy of the unit, a structure free from voids and proof against the development of voids in service, reasonable light weight, reasonable cost and pleasing appearance. With reference to the last-mentioned requirement, he observed that an attractive exterior of power plant equipment has a psychological effect on the operating personnel in promoting good housekeeping and pride in maintaining good performance.

Discussion

Much of the discussion of Mr. Kuhner's paper dealt with the employment of explosion doors on units fired with pulverized coal, oil or gas. While the insurance companies appear to insist on their use, with one square foot of explosion door area for each hundred cubic feet of furnace, the general opinion of those present was that their value is uncertain, and that it is very difficult to design such a door combining tightness with minimum inertia. The question was also raised as to why steel casing panels could not be made larger, to reduce the number of joints, and welded instead of employing so many small bolts. To this the author replied that shop facilities, transportation and handling limited the size of the panels and that field welding of such light steel had been tried but without much success.

Turbine Lubrication

C. Dantsizen, Works Chemist of the General Electric Company, in a paper entitled "Lubrication of General Electric Steam Turbines," pointed out that his company issues relatively broad recommendations for turbine oils because the oils may have a variety of physical characteristics and still function well in steam turbines. It is specified that the oil should be a petroleum derivative free from water, sediment, soap and resins or any materials which in service may prove injurious to the oil or to the turbine with its accessory equipment. The other recommendations are contained in Table 1.

TABLE 1—RECOMMENDED LUBRICATING-OIL SPECIFICATIONS FOR TURBINE-GENERATOR SETS

Properties	Land and Marine Direct-Connected Turbine-Generator Sets	Land Gear Sets and Oil-Ring Lubrication, Turbine-Generator Sets	—Marine Turbines— Auxiliary, Geared Generator Sets	Propulsion, Geared Sets
Saybolt viscosity, sec:				
at 100 F	140–170	280–325	280–325	.....
at 120 F	.....	.....	.....	220–260
at 210 F (approx)	43	49	49	55
Flash point, F (min)	330	350	350	360
Neutralization number	0.05 Max	0.05 Max	0.05 Max	0.05 Max
A.S.T.M. steam-emulsion number	90 Max	90 Max	90 Max	120 Max
Maximum viscosity before starting, sec	800	800	800	800
Minimum oil temperature before starting, F	50	70	70	85
Operating bearing-inlet oil temp, F	110–120	110–120	110–120	110–120
Operating bearing-outlet oil temp, F	140–160	140–160	140–160	140–160
Minimum oil-tank temp, F	130	130	130	130

The value of the organic-acid content of an oil, when expressed as the number of milligrams of caustic potash

required to neutralize the acids in one gram of oil, is the neutralization number of the oil. The higher the neutralization number, the greater of course is the acid content of the oil.

These specifications, prepared to include the well-tested oils of many companies, are so broad that they include some poor oils as well as the good ones. The oil selected for use should have a good service record. This need not hinder new developments in the production of turbine oils for most oil companies can test their products in their own turbines before placing them on the market.

It has been noticed lately that new turbines with new turbine oil were the ones which sometimes corroded, while old turbines with used oil never corroded. The company found that many new unused oils will, when agitated with water, allow rust to form on iron, whereas oil which has been in use in the same turbines for several years will inhibit rusting. They also found that the used turbine oil is an effective rust inhibitor when mixed with new oil in proportions as low as 1 part old oil to 99 parts new. It is of interest to note that these used oils have higher neutralization numbers than is specified for new oils. As an oil slowly oxidizes in use, organic acids are gradually formed and the neutralization number rises.

In the Company's laboratory it was found that the rust-inhibiting quality of turbine oil is in some way connected with the formation of hydrophilic groups by oxidation of the oil. Following Dr. Langmuir's procedure with oil films on distilled water, the investigators found that new turbine oils which permitted iron corrosion in the laboratory tests did not spread when dropped on water, whereas a drop of the oil used for several years in the factory turbines spread over the surface of the water very rapidly. Continuing the tests to see what molecular-weight organic acids might inhibit rusting and what ones give rise to rusting, it was found that the low molecular-weight acids were rust producers; while complete protection was found with the same percentage of acids whose molecular weight was 116 and above. The results of the tests indicating the relative rusting and rust-inhibiting qualities of 0.25 per cent of various organic acids in white medicinal oil are given in Table 2.

TABLE 2—RESULTS OF CORROSION TESTS ON STEEL SPECIMENS

	Carbon Atoms in Acid	Molecular Weight of Acid	Percentage of Surface Rusted
No acid	...	...	5
Formic acid	1	46	100
Acetic acid	2	60	100
Propionic acid	3	74	50
Butyric acid	4	88	20
Valeric acid	5	88	2
Caproic acid	6	116	0
Caprylic acid	8	144	0
Palmitic acid	16	256	0
Stearic acid	18	284	0

Condenser Tube Corrosion

The second paper at this session, presented by **C. W. E. Clarke,** United Engineers & Constructors, Inc., **A. E. White** and **C. Upthegrove,** University of Michigan, described tests conducted at Narragansett Electric Company.

One of the main difficulties in the development of surface condensers has been corrosion of tubes. Many of the large public utility and industrial power plants are located where the condensing-water supply is contaminated by sewage, industrial waste and gases, all of which make for corrosive water. The increase in temperature and reduction in pressure within condenser tubes releases corrosive gases which are the chief cause of tube deterioration. Various methods have been utilized to attempt to remove these gases before they can act on the cooling surfaces; but for the most part they have been unsatisfactory.

In an attempt to determine the best material for condenser tubes for the extension of the Narragansett Electric Company, it was decided to conduct an extensive test on various materials in a way that would as nearly as possible duplicate the conditions actually existing in a working condenser.

According to available information, Admiralty-metal, aluminum-brass and cupronickel tubes were selected as the ones most likely to give good service. A miniature condenser was used, as shown in Fig. 8, and tubes of each of the three materials, as well as a bronze tube, were installed as indicated in the cross-section. The

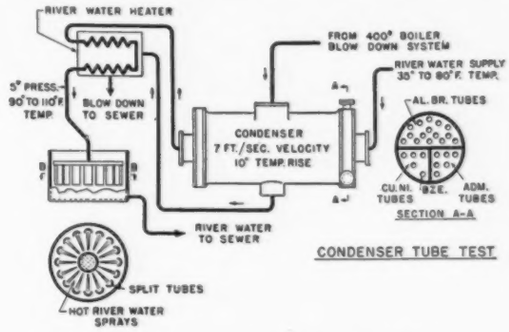


Fig. 8—Arrangement of Test Condenser

inlet water box was fitted with barriers so that the water could not come in contact with more than one type of tube. River water was passed through the tubes at a velocity corresponding to that expected in the actual condenser installation and blowdown water from the 400-lb blowdown system was admitted to the steam space.

At the same time as the condenser test, an impingement test was performed, as shown in plan *B-B* of the figure. The river water from the test condenser was heated to 90–110 F and then sprayed against the inner surface of split-tube samples.

The major emphasis was placed on the results of the above two tests; however supplementing these were mercurous-nitrate, flattening, expansion and tensile tests. No details with regard to the mercurous-nitrate, flattening or expansion tests were included in the paper.

During the condenser-corrosion test the water velocity was 7 ft per sec, and the water temperature ranged from 35 F to 80 F during the 22 months of the test. On completion of the test run the tubes were removed from the condenser and examined for corrosion. The results of this test were plotted graphically for each tube in order of decreasing resistance to corrosion and so scaled as to provide nine classifications.

Following the test, the tube pieces in the impingement apparatus were examined for resistance to impingement attack. Measurements were made of minimum wall thickness at the point of maximum wear for each tube. The ratings were set up on an arbitrary basis in which maximum resistance is indicated by 1, and minimum by 9.

Metallographic examinations of the test tubes indicated that there was little or no definite tie-up between variations in microstructure and corrosion resistance.

In conclusion the authors included among their observations that, on the basis of the particular conditions pertaining to this specific investigation, aluminum-brass is superior in its corrosion resistance to the other metals tested, and microstructure, as such, does not appear to be a controlling factor. A hard-drawn or annealed material may show equally good corrosion resistance qualities. Internal stresses of an order to produce cracking, under the conditions of the standard A.S.T.M. mercurous-nitrate test, do not necessarily decrease the corrosion resistance of the tubes, nor does their absence necessarily increase the corrosion resistance. It should not be inferred from this conclusion, however, that tubes should be furnished under such conditions of internal stress that they will crack in the mercurous-nitrate test. It is realized that expanding tubes in the tube sheets produces local stresses at these points but this is felt to be the lesser of two evils. Proper manufacturing procedure is, beyond any question of a doubt, an important factor in the production of highly corrosion-resistant tubes.

Solving Pipe Problems

At the Wednesday afternoon session on Power-Applied Mechanics, **Fred M. Hill,** Commonwealth and Southern Corporation, explained a mechanical method of solution of pipe problems for cases involving temperature expansion.

With the general acceptance of high pressures and high temperatures in steam-power-plant design, has come the need for accurate, reliable and rapid methods of calculating the stresses and reaction caused by temperature expansion. The mathematical routine of determining these stresses involves much laborious and complex calculation.

The close agreement between the test results and the mathematical calculations appears to justify the adoption of this test method. It consists of small models of piping systems made of solid, die-drawn steel rods suspended in a metal frame, with one end fixed, in such a manner as to simulate the actual proposed installation.

Ball-bearing pulleys are used for load applications, and micrometer heads at various points are used for measuring deflection and rotation. The free end of the model is equipped with an assembly of three moment arms extending in the usual coordinate directions X, Y and Z, and a micrometer head fitted with a carrying ring and four adjustable needle points.

Before the test all needle adjustments are brought into alignment and the graduated micrometer sleeves are set at zero. A scale part of the pipe expansion is now set off in the three coordinate directions on the micrometers at the free end of the model. Forces are applied to each of the moment arms in the proper amount and location, determined by trial, to realign the model in all directions. The free end of the model now assumes the same relative position of the stressed installation.

The formulas for conversion of model reactions are:

For forces

$$\frac{F_p}{F_m} = \frac{E_p}{E_m} \times \frac{I_p}{I_m} \times \frac{\Delta_p}{\Delta_m} \times S^3$$

For moments

$$\frac{M_p}{M_m} = \frac{E_p}{E_m} \times \frac{I_p}{I_m} \times \frac{\Delta_p}{\Delta_m} \times S^2$$

in which

F = Applied load, lb
E = Modulus of elasticity, lb per sq in.
I = Moment of inertia, in.^{4}
Δ = Deflection, in.
S = Ratio of lengths of model to pipe
M = Moment, in.-lb
p = Subscript indicating pipe
m = Subscript indicating model

This method is thought to provide time saving advantages over mathematical methods for complex pipe runs but not for simple pipe runs in one plane having two or three 90-deg bends when only the end reactions are sought.

Effect of Grain Size in Steam Piping

A. E. White, Consulting Engineer, The Detroit Edison Company, Director of Engineering Research, University of Michigan, and **Sabin Crocker,** Senior Engineer, The Detroit Edison Company, presented a paper on the subject, "Effect of Grain Size and Structure on Carbon-Molybdenum Steel Pipe." The paper gives the results of an investigation sponsored by The Detroit Edison Company at the University of Michigan for the purpose of studying these properties in steam pipes for their relation to high-temperature creep properties at 925 F. Pipe specimens were obtained from eight different heats of carbon-molybdenum steel, six being made by the open-hearth and two by the electric-furnace process, and an attempt was made to correlate the respective creep strengths at this temperature with other significant properties obtained through short-time tests. From the tests it is apparent that grain size alone is not a significant factor, but that if the carbide structure is of a Widmanstätten type with grain sizes ranging from 2 to 7, the steel will have good high-temperature creep properties. The steel must be properly killed to obtain the desired structure. A method to determine this is to normalize from around 1700 F.

A discussion following presentation of the paper brought out the following interesting statements. It is to be expected that a change in the structure of the pipe due to heat treatment will bring about a corresponding change in the rupture strength. The steel mills are prepared and ready to supply pipe of the required grain size. Steam pipe having the above-mentioned carbide type and grain size can be expected to show a life of thousands of hours at 925 F. The aluminum content of the test specimens was varied but showed no apparent effect upon the properties of the pipe.

Power in Ships

Under the joint auspices of the A.S.M.E. and the S.N.A. & M.E. a symposium on Thursday evening was devoted to marine power plants, in which short papers were given on boilers by **E. G. Bailey** and by **L. M. Rakestraw;** on turbines by **E. D. Dickinson** and by

J. A. Davies; and on condensers by **Paul Bancel** and **H. E. Carleton.**

The speakers, as well as numerous discussers, all stressed the fundamental similarity of marine and stationary power and the opportunity for marine and stationary engineers to learn from one another; also, the marked advances in marine practice during the last ten years in which marine engineers appear to have broken away from tradition. Discussing this phase of the subject, Mr. Bailey observed that although designers of land power plants have sometimes striven for too high efficiencies and their methods of evaluation usually do not follow fixed standards, they have generally been research minded, in contrast to the usual conservatism of the marine engineer.

Reviewing marine advances in the last decade, Mr. Rakestraw pointed to increases in boiler efficiency from 78 to 88 per cent, to increases in steam pressure to 600 lb and to advances in steam temperatures to 750 and 800 F or even higher in some recent ships; also to the employment of such refinements as combustion control. He showed that the bent-tube boiler was ideally suited to marine service and that excellent performance is being attained in merchant service with small completely water-cooled furnaces employing heat releases of 30,000 to 50,000 Btu per cu ft. Whether comparable results can be attained in naval practice with much higher heat releases remains to be seen. Air heaters are now being installed to supplement economizers where more than three stages of steam extraction are employed.

Details of design for stationary and marine turbines are similar, according to Mr. Davies, although lack of standardization in the marine field has proved a handicap and astern operation makes for some complication. Mr. Dickinson stressed the importance of reliability and efficiency and pointed out the severe mechanical stresses to which a marine turbine may be subjected with movement of the ship and the thermal stresses incurred during maneuvering. The application and development of reduction gears have made possible turbines of smaller dimensions and thus reduced stresses in the shells.

Contrasting marine and stationary problems, Mr. Carleton mentioned that although the power requirements of ships are increasing, the space usually alotted to the power plant is decreasing. Because of limited headroom marine condensers are usually bolted directly to the turbine exhaust, hence the distance between the low-pressure blading and the top condenser tubes is small and often introduces flow distribution problems. While both single- and two-pass condensers are employed, practice favors the latter as the piping arrangement is less complicated. Some vessels with single-pass condensers employ scoops for the circulating water supply, although pumps have to be used when running at low speed or astern. It is common to use about one square foot of condenser surface for each 7 lb of steam condensed, which amounts to about one square foot per horsepower developed.

Mr. Bancel stated that the present practice of his company was to roll the condenser tubes at both ends and provide an expansion joint in the condenser shell. Commenting on condenser tube materials, he cited 21 condensers, aggregating approximately 62,000 sq ft of surface and employing aluminum-brass tubes which had been in service without tube replacement for 9 yr.

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Water-Conditioning Methods and Trends

By C. E. JOOS
Manager Apparatus Div.,
Cochrane Corporation

The author enumerates the essential requirements that determine the selection of the proper treatment and describes the principal methods of external conditioning in general use. The application, limitations and advantages of each in meeting specific conditions are discussed, as is also the combination of various processes.

THE ART of conditioning boiler feedwater has continued to meet the ever more exacting demands of the modern high-pressure steam generator. Within the past ten years it has taken on a more scientific aspect, and equipment now being designed and installed would have been considered unnecessary for the comparatively low pressures of the previous decade. Today the engineering public does not have to be educated as to whether or not a water-conditioning system is justified economically, for it is an absolute necessity, but thought must be given as to the type of system or process to be used.

As a typical example of the trend toward water-conditioning apparatus, an inquiry was recently received concerning external treatment of a water having only 6 ppm hardness and a total mineral solids content of less than 13 ppm. Not many years ago this would have been considered ideally suited for boiler feed, as it would respond beautifully to various internal treatments. Today, however, where 1200-lb pressure boilers are to be fed entirely with such water, external treatment is required. The present discussion will be confined to external treatments.

Requirements of a Balanced Treatment

The essential requirement which any feedwater-conditioning method should meet, and which determines the water-conditioning process and the equipment to be used, may be enumerated as follows:

1. Maintenance of clean evaporating surfaces. Achieved by reducing calcium, magnesium and silica to low limits and by maintaining a chemical environment that will prevent the formation of adhering sludge in the boiler.
2. Protection against corrosion of economizers, boilers, stage heaters, condensers, piping, etc. Achieved by the maintenance of satisfactory pH values, by reduction of dissolved oxygen to insignificant values, and by removal or reduction of ammonia, carbon dioxide and other corrosive gases.
3. Control of carry-over. Achieved by reduction and control of solids and alkalinity, to keep foaming and priming to a minimum.
4. Protection against embrittlement. Promoted by the maintenance of the sulphate-to-carbonate ratios recommended by the A.S.M.E., by the introduction of inhibitors and by reduction of silica.
5. Low cost of installation and of operation. This includes cost of chemicals, cost of labor, space requirements and cost of equipment and of its installation.

Methods of Conditioning Feedwater

The available methods which are in more general use for obtaining these objectives and some of their modifications are:

1. Evaporators.
2. Hot-process water softeners, with the following treating agents:
   (*a*) External treatment with lime and soda ash, combined with an internal treatment of phosphate.
   (*b*) External treatment with lime and soda combined with external treatment of phosphate.
   (*c*) Phosphate and caustic soda.
   (*d*) Phosphate, magnesium oxide and caustic soda.
   (*e*) Phosphoric acid, caustic soda and magnesium oxide.
   (*f*) Lime, gypsum and supplementary phosphate.
   (*g*) Lime, magnesium oxide and secondary phosphate.
3. Zeolite.
   (*a*) Alone, without pre- or post-treatment.
   (*b*) Pre-treatment with lime for reduction of carbonates or coagulation or clarification.
   (*c*) Post-treatment with acid.
   (*d*) Carbonaceous zeolite using either or both the acid and sodium regenerating cycles.
   (*e*) Pre-treatment with coagulants such as ferric sulphate or with magnesium salts for reduction of silica.
   (*f*) Treatment with carbonaceous zeolite, using H_2Z and Na_2Z units in combination, followed by treatments with magnesium oxide for silica removal.

[1] Based on a recent talk before the East Tennessee Section of the A.S.M.E.

Evaporators

Evaporators produce a water substantially free of solids, silica or other detrimental constituents and require only a small amount of alkali and phosphate to correct impurities resulting from carryover, leakage, etc., in order to render it noncorrosive and nonscale forming. Where the makeup is large in amount, however, the cost of installation and of operation are real objections. In the case of an evaporator producing or making up for unreturned process steam, for example, it is necessary to bleed the turbine at a higher pressure than would be necessary if the process steam were taken directly from the turbine, which represents a definite loss in available electrical energy. There is no such thermodynamic objection where the makeup is prepared chemically, and in view of the fact that water conditioning methods are available for even the highest pressure boilers, evaporators can no longer be considered indispensable. A number of 1200- to 1500-lb plants are now in operation or contemplated using from 10 to 100 per cent makeup water, conditioned by both the hot process and the zeolite methods.

Where evaporators are used as in central stations requiring only 1 to 3 per cent of makeup, a water conditioning system is generally needed for preparing the evaporator feed and its selection is based on the same factors that govern the selection of a system to protect steam boilers. In most recent installations chemical treatment methods are relied upon rather than cracking off. As compared with cracking they give a continued sustained capacity and make it possible to install somewhat smaller evaporating equipment.

Removal of Silica

The removal of silica from feedwater is receiving much attention just now, as it is coming to be recognized as presenting the following objectionable possibilities:

1. Formation of sodium-aluminum silicate scale of the analcite type, particularly so if it exists in the presence of alumina.
2. When present in carry-over from evaporators or steam boilers, it has frequently been found to form hard turbine-blade deposits which required scraping for removal.
3. It has been proved that silica in the presence of caustic accelerates embrittlement, while pure caustic alone is not embrittling, and becomes so only when silica is present. Silica can be removed by utilizing the magnesium hardness in the raw water or by adding coagulants, such as ferric sulphate, magnesium sulphate or magnesium oxide.

Silica can be removed either in the cold or in the hot, and in the cold-process softening systems ferric sulphate is quite commonly applied, although by producing sodium sulphate it increases the total solid content considerably. Dolomitic lime or magnesium oxide do not have this objection, and at the same time remove silica effectively.

With the hot-process softener, magnesium sulfate is used wherever the by-product, sodium sulphate, is desired in the boiler water, or magnesium oxide where the sodium sulphate may be objectionable.

Silica does not react with the reagents in strictly stoichiometric relationships. Recirculation of sludge in either cold- or hot-process softeners is desirable to facilitate contact and to remove silica with smaller quantities of chemicals.

Zeolite Water Softeners

Formerly, only natural green-sand and synthetic zeolites both high in silica, were available, but these substances are now in many cases being displaced by carbonaceous zeolites, which are free of soluble silica and can be regenerated with sulphuric acid, as well as with salt; thus opening up new fields. The carbonaceous zeolites are manufactured from a number of substances, but, most commonly from lignite. By the addition of approximately five parts of concentrated sulphurc acid to each part of lignite, and heating to above 150 C, a chemical reaction takes place, with considerable evolution of sulphur dioxide. The volatile substance of the lignite combines with the sulphuric acid or in chemical

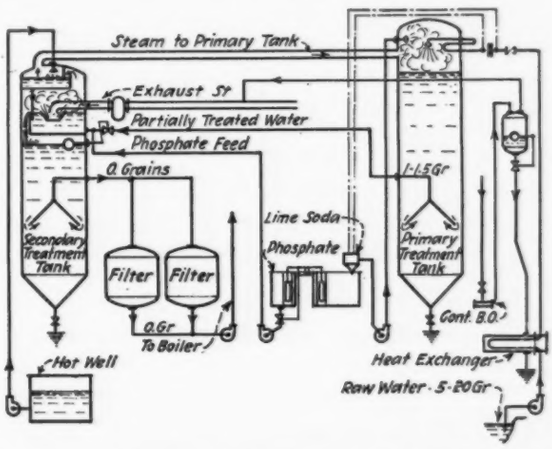


Fig. 1—A combination lime-and-soda zeolite softener for 100 per cent makeup boiler plant operating at 900 lb per sq in.

terms is "sulphonated." The resulting material is then washed and graded and after some additional processing is satisfactory from the standpoint of exchange.

A synthetic resin type of zeolite, quite different from the carbonaceous zeolite, and derived from phenol and formaldehyde, has exchange properties similar to those of the carbonaceous material, except in a much higher degree. Whereas the carbonaceous zeolites have the capacity to exchange 6000 to 12,000 grains per cubic foot depending upon the amount and method of regeneration, the synthetic resin material has an exchange capacity of approximately 25,000 grains per cubic foot. It is particularly well adapted to the softening of hard water, or where it is desirable to lengthen the periods between regenerations.

In contrast to the alumina-silica zeolites the new zeolites are acid-resisting and free of silica, and can be regenerated with an acid, opening up possibilities of reducing alkalinity heretofore impossible with green-sand or synthetic silica-bearing zeolites, which would be disintegrated by the acid.

In general zeolites exchange one metal for another, and since hydrogen in its chemical reactions is classified as a metal, the zeolite regenerated with an acid will impart to the conditioned water acids corresponding to the acid

radicals of the salts originally present. Carbonates, for example, will be reduced to H_2CO_3, which can be broken up and removed entirely as CO_2 by aeration. Below are tabulated the chemical reactions that occur in the sodium and the acid cycles. While any mineral acid might be used for regeneration, sulphuric acid is preferred, because of its cheapness.

CARBONACEOUS ZEOLITE SOFTENER CHEMICAL REACTIONS

SODIUM CYCLE

Softening

(1) $\left.\begin{matrix}Ca(HCO_3)_2\\Mg(HCO_3)_2\\CaSO_4\end{matrix}\right\} + NaZ \ldots\ldots\ldots\ldots \left.\begin{matrix}Ca\\Mg\end{matrix}\right\} Z + \begin{matrix}2NaHCO_3\\Na_2SO_4\end{matrix}$

Regeneration

(2) $\left.\begin{matrix}Ca\\Mg\end{matrix}\right\} Z + 2NaCl \ldots\ldots\ldots\ldots\ldots\ldots Na_2Z + \left.\begin{matrix}Ca\\Mg\end{matrix}\right\} Cl_2$

ACID CYCLE

Softening

(3) $\left.\begin{matrix}Ca(HCO_3)_2\\Mg(HCO_3)_2\\NaHCO_3\\CaSO_4\\2NaCl\end{matrix}\right\} + H_2Z \ldots\ldots\ldots \left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z + \begin{matrix}H_2CO_3\\H_2SO_4\\2HCl\end{matrix}$

Regeneration

(4) $\left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} Z + H_2SO_4 \ldots\ldots\ldots H_2Z + \left.\begin{matrix}Ca\\Mg\\Na_2\end{matrix}\right\} SO_4$

Zeolite Water-Softener Combinations

PRE-TREATMENT

Before passing surface water supplies through a zeolite softener, it is generally necessary to give them a preparatory treatment. For example, if the water is initially turbid, relatively high in silica and has a high carbonate content, the silica and carbonate can be reduced by treatment in a cold-process softener with lime and a coagulant, such as magnesium oxide, magnesium sulphate or ferric sulphate or dolomitic lime, which contains approximately 60 per cent calcium oxide and 40 per cent magnesium oxide. The water is then filtered and the pH value adjusted, usually by acid, after which it is satisfactory for zeolite softening.

Fig. 1 gives the flow diagram of a system designed for the preparation of 100 per cent makeup in a 900-lb pressure plant. Lime and soda ash are used, because soda ash was found to be cheaper in this instance than the equivalent amount of salt that otherwise would have to be used in the carbonaceous zeolite units. By reason of accelerating the chemical reaction by seeding with previously formed sludge, softening requires only one hour, whereas with older methods it would require four in cold water. After filtration the pH value is adjusted, being reduced from approximately 10 to 7.5, and the water is then softened by passing it through five 10-ft diameter gravity zeolite softeners. The softened water is stored in steel tanks and then delivered to a deaerator and to the boilers, at which point it is treated with phosphate and sulphite.

Frequently combination softeners are fitted with automatic control, in which operations are made automatically or semi-automatically, including the maintenance of a constant pH value in the treated water by regulating the lime for the reduction of carbonates. Filter and zeolite softener valves are pneumatically operated through electrically-actuated pilot valves controlled by mechanism on the panel-board. Water-conditioning equipment of this type has been supplied for conditioning water for evaporators used in connection with a 1500-lb steam generator.

Use of the H_2Z and Na_2Z Units in Combination

Where the water is clear, but has a relatively high carbonate content, which should be reduced, part of the water can be passed through a hydrogen-regenerated softener and part through a sodium-regenerated softener, the proportions depending upon the alkalinity desired

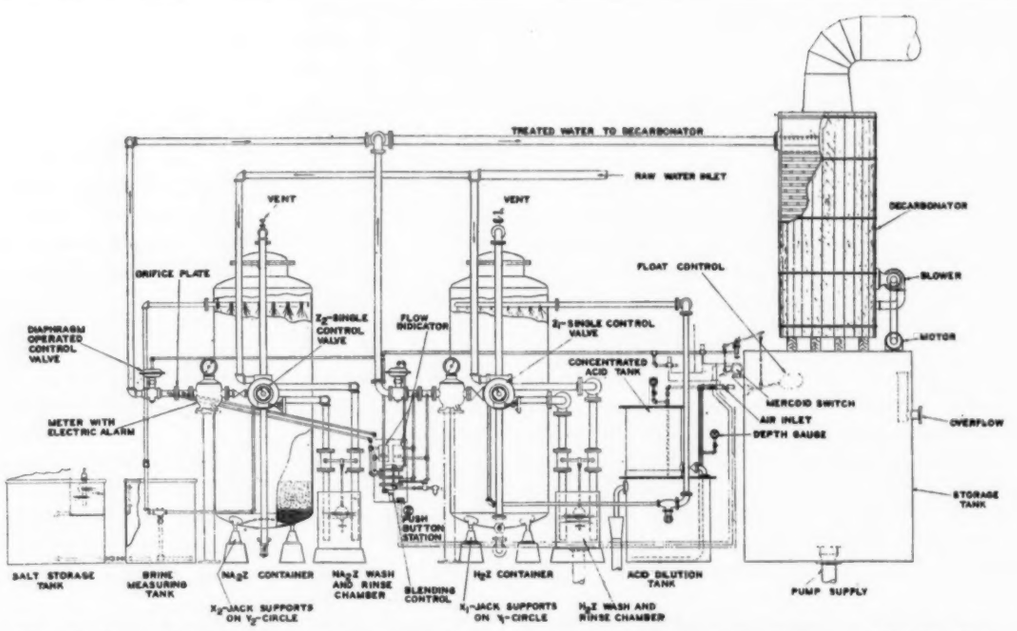


Fig. 2—A combination of acid-regenerated and sodium-regenerated softeners, with blending and safety controls and decarbonator for removal of CO_2

after the two supplies have been combined. All salts entering the hydrogen unit are converted to their respective acids in accordance with reaction 3.

In the sodium-zeolite softener the salts are converted to their corresponding sodium salts, as shown by reaction (1); that is, carbonates to sodium bicarbonate, sulphates to sodium sulphate, etc. The high alkalinity of the sodium-zeolite water is corrected by mixing the two water supplies. That is, the sodium bicarbonate reacts with the hydrochloric and sulphuric acids, produced by the H_2Z unit, and results in the generation of considerable CO_2, with a corresponding reduction of the sodium alkalinity. The CO_2 is removed by passing the water over a decarbonator in which the carbon dioxide will be reduced to a few parts per million. With such a system it is necessary to proportion the two waters continuously, which is done automatically, with a safety provision for immediately closing down on the H_2Z unit in the event of failure or shutting off of the Na_2Z unit, to prevent acid from entering the boiler-feed supply. Fig. 2 shows the arrangement of such a system. The finished water is low in hardness, of approximately 2 to 3 ppm, depending on the water supply and on the method of operation. Such units can, however, be made to give a hardness of not more than 1 ppm, if only 80 to 85 per cent of the normal run is taken.

After the decarbonation operation, the softened water will have a low pH value, generally in the neighborhood of 6 to 6.5, and should be deaerated preferably through an atomizing type deaerator, which is less subject to corrosion that are tray types.

Post-Acid Treatment

Carbonaceous-zeolite softeners are also combined with a post-acid treatment in which the high alkalinity is reduced by sulphuric acid. The CO_2 thus produced is removed by a decarbonator. While this produces a water higher in solids, it does use more simple equipment, and although it may require more frequent blowing down, in many cases it is economically justified. Many such systems are in service with green-sand zeolite softeners, particularly in connection with central steam-heating plants.

The carbonaceous zeolite softener does not remove silica, so high silica-bearing waters require precipitation methods. Where the water is turbid, pre-treatment with lime and coagulant is given. Where turbidity is not excessive, but the silica is high, or where the water contains natural sodium carbonate, the water can first be passed through a combination hydrogen and sodium exchanger, reducing the sodium carbonate and converting the calcium and magnesium salts to the corresponding sodium salts. After control of the alkalinity by blending, this water is passed through a decarbonator for reduction of CO_2 and then through a hot-process softener for removal of silica by treatment with magnesium oxide and caustic soda. The total solids in such water supplies are thereby reduced to a lower quantity than is possible by any other means. Regeneration of the zeolite with acid affords the only means of removing sodium bicarbonate without the production of a by-product, while the use of magnesium oxide for silica removal provides a means of reducing this without at the same time increasing the total solid content.

Anion Exchangers

The synthetic resin zeolite offers certain entirely new possibilities. We have discussed the exchange of calcium, magnesium and sodium for hydrogen; these are the "cations." The "anions" are the chloride, sulphate and nitrate radicals and can be exchanged for OH with properly prepared zeolite, giving what might be termed "anion exchange." Thus, we have the possibility of removing the entire mineral substance in feedwater, with the exception of silica. The chemical reactions that occur in the anion exchanger are as follows:

$$\left.\begin{matrix} H_2SO_4 \\ HCl \\ HNO_3 \end{matrix}\right\} + ZOH = H_2O + \begin{matrix} Z\ SO_4 \\ Z\ Cl \\ Z\ NO_3 \end{matrix}$$

A few installations of this type have been made, generally of small capacity, and the process is not as yet offered commercially.

Hot-Process Softener Using Lime and Soda With Supplementary Phosphate Treatment

The hot-process softener is the most versatile of all, since the conditioning of the water is brought about through precipitation and the designer has a selection of any number of precipitants, depending upon the chemical character of the water, without radical change in the size of that equipment, irrespective of the process used.

The reagents used in the hot-process softener are most commonly lime and soda ash, followed by an internal treatment of phosphate, customarily pumped directly to the boiler. The hot-process softener using lime and soda ash is generally selected for clarification and hardness reduction of turbid waters, or for softening and clarifying high carbonate waters. The costs of chemical reagents for treating high carbonate are low, for the reason that lime, the cheapest of all water-softening agents, is the predominating chemical.

For high-pressure boilers operating up to, say, 900-lb pressure, lime-and-soda treatment with supplementary phosphate treatment is common. It gives a reasonably low hardness, which can be adjusted by varying the excess sodium carbonate. Thus, to obtain a water of lower hardness it is only necessary to increase the amount of soda ash, which can be done in one or two ways; either by increasing the soda ash supplied to the chemical feeding equipment or by recirculation of the concentrated boiler water. The latter practice is desirable if the water is low in solids, as it increases the alkalinity in the sedimentation tank, where alkalinity is needed for hardness reduction, without increasing alkalinity of the boiler water, for the reason that the water is simply withdrawn from the boiler and returned to it without reduction or addition. Equipments are now being offered in which the water for the recirculation is taken from the heat exchangers of continuous blow-off equipment and delivered to the sedimentation tank in proportion to the makeup.

Water softeners of the type just mentioned are customarily operated to have a residual hardness of one-half to one grain per gallon, which does not produce a great amount of sludge and the sludge formed is flocculent and generally nonadherent. Supplementary treatment with phosphate is, of course, necessary, the phosphate being maintained in the boiler at an excess generally of 10 to 50 ppm, in terms of tri-sodium phosphate.

Phosphate is proportioned in accordance with flow of makeup, either directly and continuously to the boiler, or intermittently into the suction of the boiler-feed pump. The method of introduction to be selected depends upon the type of equipment in the plant. For example, in the absence of economizers or stage heaters, it is satisfactory to introduce metaphosphate intermittently into the suction of the boiler feed pump, whereas if such equipment is present phosphate should be pumped directly to the boilers, as otherwise deposits will accumulate in the heaters, etc. This type of conditioner has been furnished in very large capacities, up to 320,000 gph, supplying practically 100 per cent makeup water for 900-lb boiler plants. With such capacities it is possible to arrange filtering equipment for automatic back-washing. Thus, the system effects a considerable reduction in operating labor in that the only attention required is in the charging of the chemicals and the testing of the water to determine the character of the treatment. For very large capacities, this system offers perhaps the best way of securing a balanced treatment at the lower cost for installation and operation.

Two-Stage Softening

The secondary or two-stage softener provides for external treatment of the residual hardness of lime-and-soda softened water in a separate compartment in the same sedimentation tank, or in an independent sedimentation tank. A residual hardness of $^1/_2$ to 1 grain per gallon can thereby be reduced to a few parts per million, giving a very soft water for boiler makeup.

Fig. 3 illustrates a two-stage water softener for preparing approximately 50 per cent makeup for a 600-lb boiler plant. In this plant the high carbonate and turbid river supply is first treated with lime and soda ash, decanted to a second tank where it joins oily condensate and the combined waters are then deaerated through a single atomizer. At this point the phosphate is introduced and the residual hardness is precipitated, forming the floc for coagulation of the water, and after passage through anthracite filters the water is delivered directly to the boilers.

The method of oil removal here shown is not widely utilized as generally it is better to coagulate and remove the oil from the condensate prior to heating and to keep the condensate apart from the treatment of the makeup water. In this particular case, however, satisfactory conditions are maintained in the boilers without undue operating attention.

Softening With Phosphate

The lime-and-soda-ash treatment is particularly well adapted to hard water supplies, but where the hardness is but 50 ppm or less, its efficiency is not so great and a reagent is needed to precipitate the hardness to a lower degree than can be obtained with lime and soda. By using phosphate and maintaining the proper environment, the hardness can be kept down to a few parts per million, producing water equal to that produced by zeolite softening or even better on the average. For example, a water having a hardness of approximately 15 ppm, silica content of 16 to 22 ppm, is treated very effectively by the introduction of magnesium sulphate, caustic soda and tri-sodium phosphate, using the arrangement shown in Fig. 4.

Magnesium sulphate reacts with the caustic soda to produce magnesium hydrate for the removal of silica, while the phosphate precipitates the calcium as tri-calcium phosphate. Contact of silica with precipitate is promoted by the introduction of a stirring mechanism and

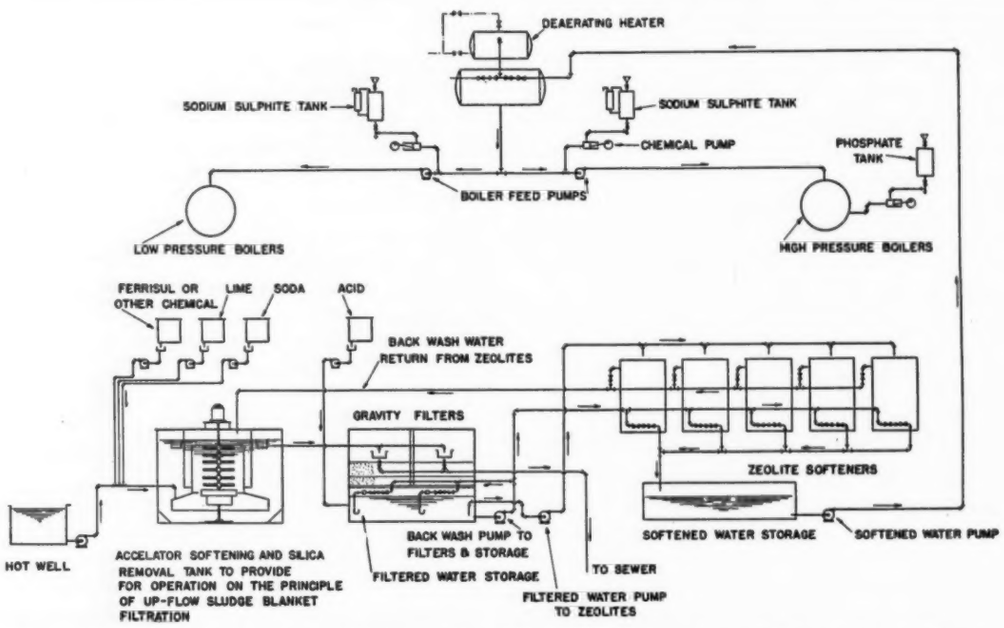
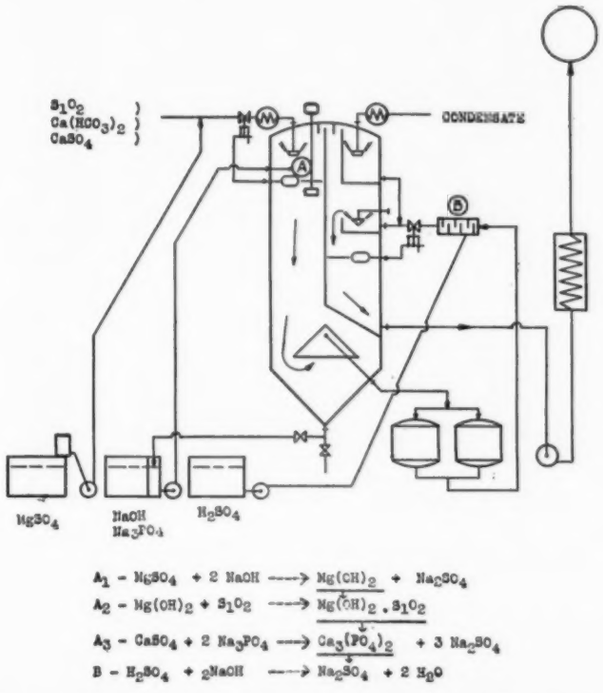


Fig. 3—Two-stage hot-process softener serving 600-lb boiler plant having 50 per cent makeup, oil being removed from condensate incidentally to softening process

recirculation of the sludge. The decanted water is then filtered and returned to the deaerating section, where a treatment with sulphuric acid is given to reduce the pH value from 10 to 8.5 or 9, insuring freedom from deposits in the stage heaters.

Operation of the high-pressure boilers with this process for almost a year has shown it to be highly efficient in the removal of silica, as no deposits of any kind have accumulated in the boilers or in the stage heaters. Recirculation of sludge is a valuable expedient, as it reduces the amount of magnesium sulphate that would otherwise have to be introduced, by as much as 50 to 75 per cent.



$A_1 - MgSO_4 + 2\,NaOH \longrightarrow \underline{Mg(OH)_2} + Na_2SO_4$

$A_2 - Mg(OH)_2 + SiO_2 \longrightarrow \underline{Mg(OH)_2 \cdot SiO_2}$

$A_3 - CaSO_4 + 2\,Na_3PO_4 \longrightarrow \underline{Ca_3(PO_4)_2} + 3\,Na_2SO_4$

$B - H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$

Fig. 4—Phosphate-softening process combined with removal of silica by magnesium sulphate and sludge recirculation; pH adjustment by sulphuric acid

Treatment With Phosphoric Acid

Inspection of the reactions of tri-sodium phosphate with carbonates will make it apparent that this treatment is open to the same objection as is treatment in the sodium-regenerated zeolite softener; in other words, there is no reduction of alkalinity. This can be overcome by the use of phosphoric acid instead of tri-sodium phosphate.

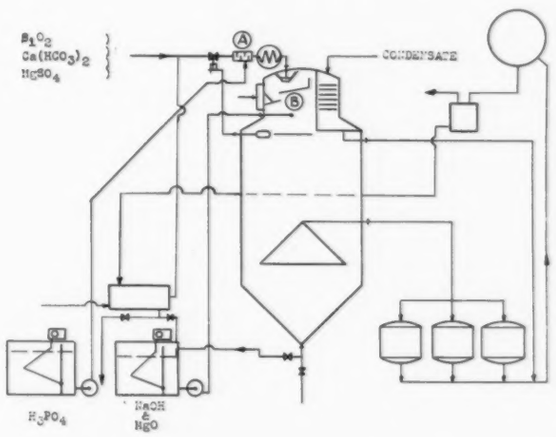
As an example, Fig. 5 shows an installation having a capacity of 700,000 lb of steam per hour, and designed to treat for 450-lb boiler pressure. The water initially contains approximately 12 to 35 ppm of silica and somewhat less than 50 ppm of hardness. In order to control the alkalinity, phosphoric acid is introduced ahead of the deaerating section, thereby liberating the carbon dioxide, which is removed in a deaerator, after which caustic soda and magnesium are introduced, precipitating the calcium as phosphate, while the silica is adsorbed by magnesium oxide. Sludge is recirculated to conserve magnesium oxide, and concentrated boiler water can be recirculated to gain additional control over alkalinity. The reactions that occur at *A* and *B* are given in the table directly below the illustration.

Two-Stage Softening With Silica Removal

In the case of the two-stage water softener shown in Fig. 6 serving for the preparation of 10 per cent makeup water for 1500-lb pressure boilers, the water originally contains approximately 100 ppm of calcium and magnesium hardness, approximately 30 ppm of sodium bicarbonate and 20 ppm of silica. The hot-process softener is designed for primary treatment with lime and magnesium oxide, the lime for the precipitation of bicarbonates and for conversion of the sodium bicarbonate to the normal carbonate, and the magnesium oxide, with recirculation of sludge, for absorption of silica. The decanted water is then treated with phosphate to reduce the hardness to zero and subsequently is filtered through anthracite.

Lime and Gypsum Treatment

Where waters contain a high content of bicarbonate, or to reduce the alkalinity, gypsum may be added along with the lime, which would reduce the sodium carbonate, and result in a by-product of sodium sulphate. A number of such installations, with magnesium salts for silica removal, are in service and a recent installation combines treatments with lime, gypsum and magnesium sulphate. Magnesium sulphate is used as the silica adsorbent in this instance, in view of its ability to reduce sodium carbonate and the necessity for increasing the sodium sulphate content in order to maintain the A.S.M.E. nonembrittlement ratios.



$A - Ca(HCO_3)_2 + H_3PO_4 \longrightarrow CaHPO_4 + 2H_2O + \uparrow 2CO_2$

$B_1 - CaHPO_4 + NaOH \longrightarrow \underline{Ca_3(PO_4)_2} + Na_3PO_4 + 3\,H_2O$

$B_2 - MgSO_4 + NaOH \longrightarrow \underline{Mg(OH)_2} + Na_2SO_4$

$B_3 - MgO + H_2O + SiO_2 \longrightarrow \underline{Mg(OH)_2 \cdot SiO_2}$

Fig. 5—Treatment with phosphoric acid and caustic soda combined with magnesium oxide for softening and silica removal; recirculation of boiler water to maintain high pH in sedimentation tank

The foregoing illustrations show how both zeolite softeners and hot-process softeners are being re-designed to attain new objectives, and how in the selection of softening equipment, all costs of chemical treatment and of operation must be considered.

Removal of Ammonia

Because of contamination of streams with sewage, destruction of brass and copper parts by ammonia is increasing in steam power plants. Reduction of ammonia in the makeup water can be effected by mechanical apparatus, similar in principle to deaerating equipment but differing from it greatly in dimensions and in arrangement of parts. In one installation the ammonia is being reduced from 5 ppm down to 0.01 ppm. This de-ammoniator is located ahead of the main station evaporator and was installed to prevent accumulations of ammonia gases in the main condenser and consequent deterioration of the condenser tubes. Trouble has occurred in evaporator condensers, stage heaters, etc. In a new plant the most economical solution would probably be the elimination of copper or copper alloys, since ammonia removal apparatus of any appreciable capacity is costly.

Oxygen From Dissociation of Steam

Another condition that has received the attention of water-conditioning experts is the corrosion of high-pressure boiler furnace tubes in the absence of dissolved oxygen in the deaerated feedwater. This corrosion has been found to be due to oxygen resulting from the dissociation of steam caused by over-heating of the furnace tube, probably attributable to faulty circulation. This action has also shown up in superheater tubes and its progress can be appraised by measurement of the hydrogen that

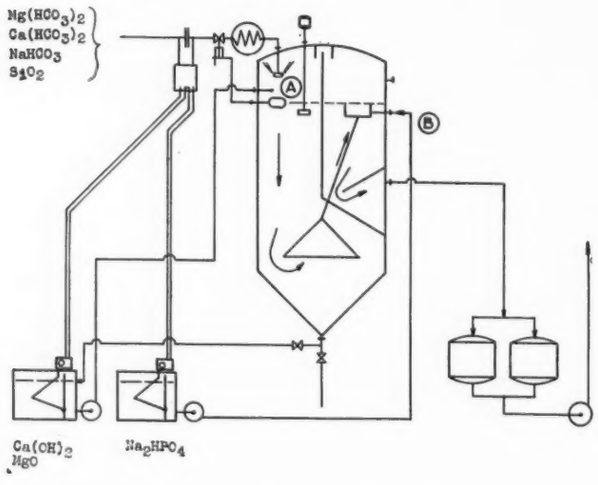


Fig. 6—Two-stage softener for 10 per cent makeup for 1500-lb boilers, combining lime treatment and magnesium oxide for pre-softening and silica removal and phosphate softening as second stage

flows out with the steam. For this purpose, a special steam sample degasifier, shown in Fig. 7 takes a sample of high-pressure steam, condenses it, thoroughly deaerates it, and provides for separating the gases from the deaerated condensate. In this apparatus the steam first enters the bottom of the right-hand chamber, deaerating the previously condensed steam by an atomizing action. The steam then passes over to the container on the left and is condensed, after which it returns to the right-hand container for re-deaeration. Thus the water is subject to an atomizing action many times, thoroughly disengaging the gas, which is removed from the left-hand chamber through the vent condenser. The latter condenses the vapor and separates out the noncondensable gases, which can be drawn to gasometric analyzing apparatus for determination of CO_2, oxygen, hydrogen, etc. The de-

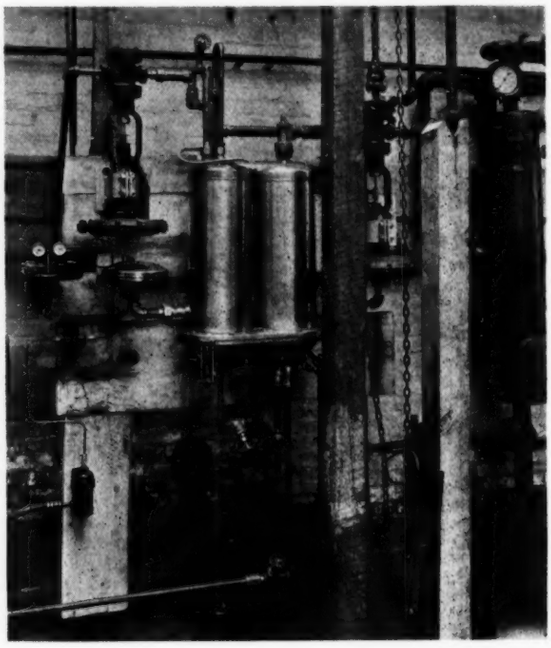


Fig. 7—Steam sample degasifier used for collection of hydrogen and preparation of sample for conductivity test

aerated condensate is so free of gases that it is suitable for use in measuring conductivity, and very little correction, if any, will apparently have to be made for such gases as ammonia. Thus, the sampler serves the dual purpose of measuring noncondensable gases in the steam and of deaerating the condensed steam and preparing it for conductivity tests to measure carry-over.

Midwest Power Conference

The 1941 meeting of the Midwest Power Conference will be held on Wednesday and Thursday, April 9 and 10, at the Palmer House, Chicago. This conference is sponsored annually by Illinois Institute of Technology (formerly Armour Institute of Technology) with the cooperation of seven other midwestern universities and local sections of the engineering societies.

The tentative program includes papers on a survey of stationary power facilities from the standpoint of defense; a résumé of present day power trends; forced circulation in American power-plant practice; modern steam-turbine design; variable-speed drives for plant auxiliaries; hydro power and the National Emergency; re-establishment of cable communication; application of recording meters and equipment; some problems in power system stability; increasing power production with present boiler facilities; and interchange contracts between industrial plants and utilities.

The Viscosity of Steam

By Dr. E. F. LEIB

Combustion Engineering Company, Inc.

IN THE *Transactions* of the A.S.M.E., November 1940, Hawkins, Solberg and Potter report their new experiments on the viscosity of superheated steam as carried out at Purdue University. These experiments cover a range from atmospheric pressure up to 1500 lb per sq in. at temperatures up to 1000 F and must be considered the most reliable data now available on this subject. In a discussion of this paper (pp. 683–684), the writer has developed the following formula for the viscosity of vapors from the kinetic theory:

$$\mu = \mu_0 \frac{\frac{v}{4b}\left(1 - \frac{b}{v}\right)^2}{\sqrt{\left(\frac{v}{4b} + \frac{3}{4}\right)^2 + \frac{\Theta}{T}} - \sqrt{1 + \frac{\Theta}{T}}} \qquad (1)$$

where μ = absolute viscosity for temperature T (F abs.) and volume v (cu ft per lb)

μ_0 = absolute viscosity for same temperature and zero pressure

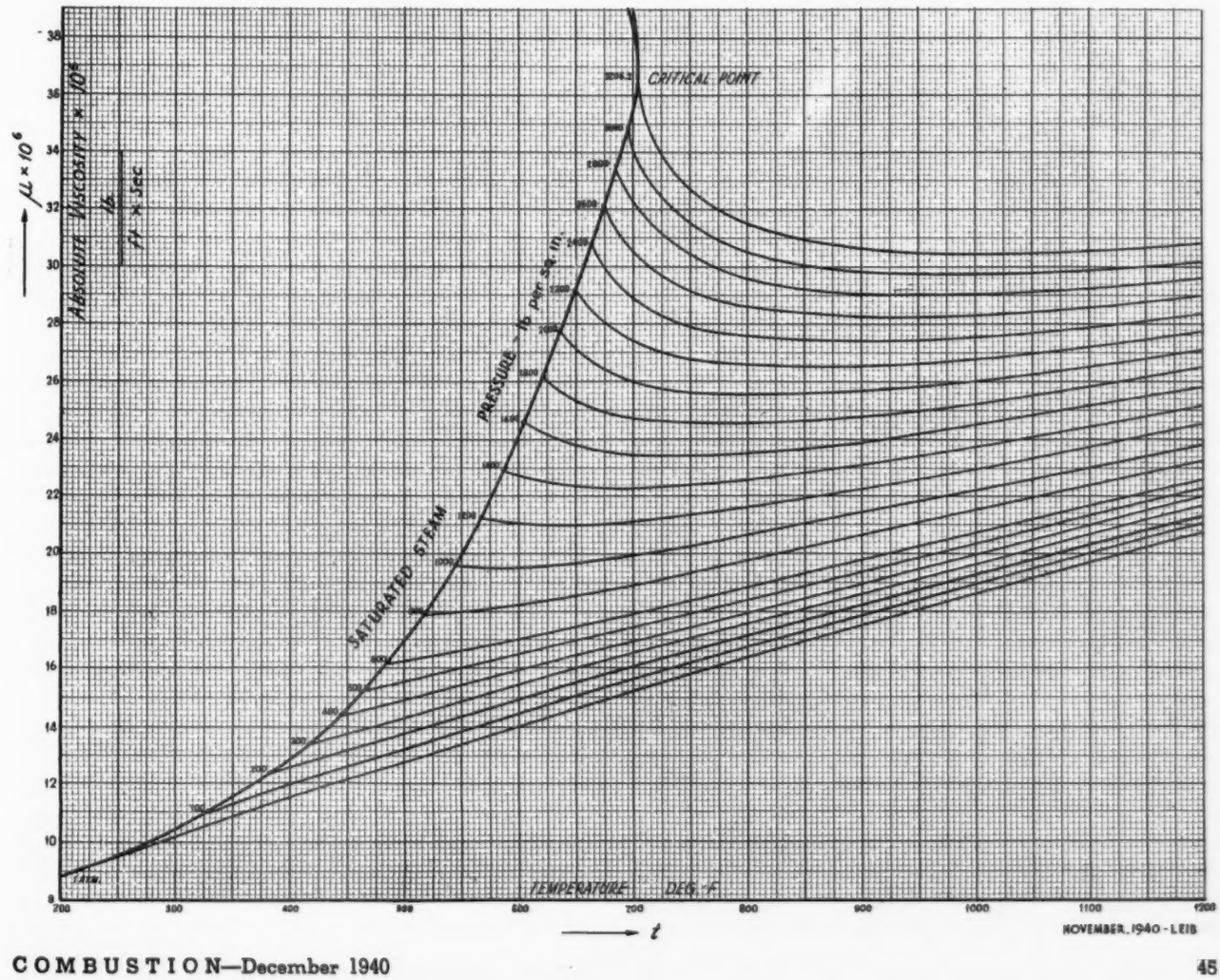
$$\left.\begin{aligned} b &= 0.016 \text{ cu ft per lb} \\ \Theta &= 19{,}000 \text{ F} \end{aligned}\right\} \text{ for } H_2O$$

The viscosity of steam in the perfect gas condition (zero pressure) can be expressed as

$$\mu_0 = 0.754 \times 10^{-6} \frac{\sqrt{T}}{1 + \frac{S}{T}} \left[\frac{\text{lb}}{\text{ft} \times \text{sec}}\right] \qquad (2)$$

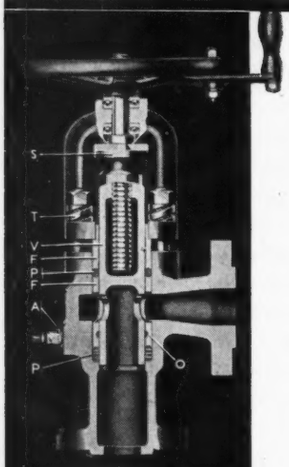
where S is the Sutherland constant, and T the temperature in deg. F abs. With S = 800 F, equation (1) gives the best agreement with the Purdue experiments for all pressures investigated.

From equation (1), in conjunction with equation (2), the viscosity for saturated and superheated steam has been calculated for the range between atmospheric pressure (14.7 lb per sq in.) and the critical pressure (3206.2 lb per sq in.) and for temperatures up to 1200 F. These values are shown on the accompanying chart.



YARWAY EQUIPPED . .

A Mark of Good Engineering



Yarway Seatless Blow-off Valve. Operation: After Valve is closed, shoulder S on plunger V contacts with upper follower gland F, forcing it down into body and compressing packing P above and below port. Annular groove O connects with Alemite fitting A for lubricating plunger and packing. Yoke springs T maintain continuous pressure through follower gland F on packing rings P.

Yarway Blow-off Valves are used singly or in tandem in more than 12,000 plants in 67 different industries . . . Regarded as a standard of quality by leading steam plant designers and builders of steam generating equipment...Selected for Federal, State and Municipal Institutions... Built for all pressures up to 2,500 lb. . . . Write for Catalog — Section B-420, up to 400 lb. pressure; Section B-430 for higher pressures.

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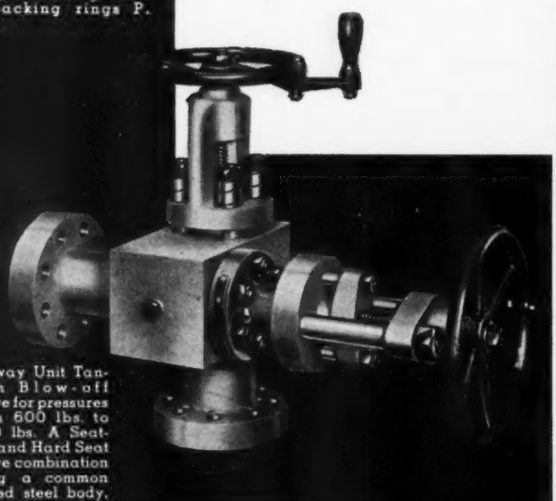

Yarway Unit Tandem Blow-off Valve for pressures from 600 lbs. to 1500 lbs. A Seatless and Hard Seat Valve combination using a common forged steel body.

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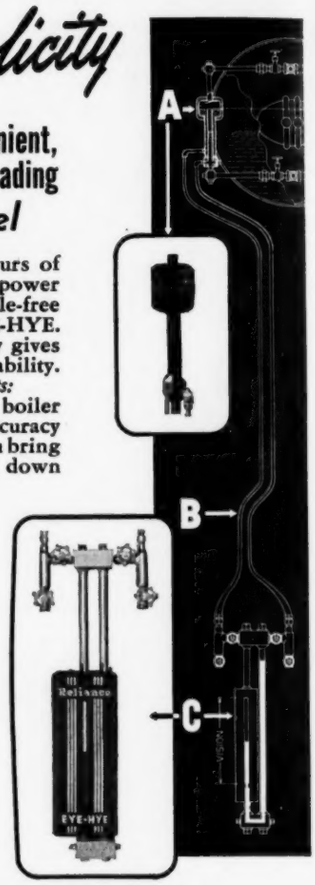

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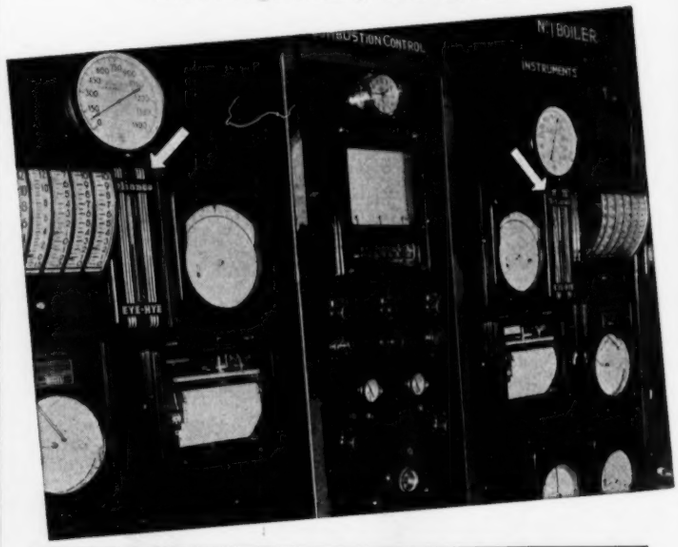

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